ABANDONMENT PLAN
FOR SOUTH BAY MINES
BP RESOURCES, SELCO DIVISION
PHASE I

DETAILED SITE ASSESSMENT
AND
ABANDONMENT APPROACH

by

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SUMMARY

It was essential for our attempted formulation of close-out measures for the South Bay Mine site to assess the existing environmental conditions. Background information was reviewed, and an Ecological Engineering approach was drafted, based on evaluations carried out between April and July, 1986. In a presentation to the Ministry of the Environment, Northwestern Region, Kenora, submissions were made respecting the approach being taken and the experiments underway (August 19, 1986). Approval in principle was obtained for the pilot demonstration in September, 1986, of Ecological Engineering measures for close-out and abandonment of the copper and zinc concentrator wastes at South Bay Mines, BP Resources, Selco Division.

A full scale investigation of the waste management area was initiated. This technical report summarizes the conditions at the South Bay Mine site and in the immediate environment of Confederation Lake after some ten years of mine operation and four years following closure of the mine (Section 4.1). The chemical/physical characteristics of the waste management area are compared to those of the natural background to assess water quality and environmental conditions in Section 4.2 of the report. Finally, in Section 4.3, site specific results of the ongoing experiments are presented, along with their rationale and purpose.

The waste management area is located in the English River drainage Basin in Northern Ontario, with typical Northern Coniferous forests, frequent wetlands and peatlands. The main parts of the site are the mine and mill site, and a dry vegetated tailings area of 14 ha with a Decant Pond of 13 ha. Boomerang Lake receives run-off from the tailings and the mine site and is therefore part of the waste management area, draining into Lost Bay, an extremely shallow part of Confederation Lake. Decant Pond, and the tailings surface, drains towards Mud Lake and outflow finally reaches Confederation Lake through an unnamed lake.

The dry tailings area was reclaimed in 1982 and the vegetation cover was evaluated in 1986. Three types of grass cover (sparse, background and dense) were differentiated for those areas where the cover persisted. In some areas the gravel fill cover overlaying the tailings, which was generally 30 to 40 cm thick, was either free of vegetation or sections of the surface were waterlogged. The thickness of the neutral fill (pH 5.8 to 6.9) and the type of vegetation cover had no relationship to the acidic (pH <3.5) tailings underneath the fill. The species composition of the vegetation cover was typical for waste sites, consisting mainly of sedges, grasses and the introduced legumes. Some areas are colonized by either acidophilic or chalciphile terrestrial mosses. Fertilization experiments on the grass cover indicated that above-ground biomass could be increased with regular fertilizer application. However root penetration through the fill would also increase, thereby counteracting any potential benefits of reduced infiltration of precipitation to the tailings by increased organic cover.

The exposed shores of Decant Pond are being colonized mainly by indigenous grass and moss species. Although metal concentrations in the surface material are somewhat elevated, natural recovery of these shores is not impaired. Some remedial actions are required however, to cover exposed oxidizing tailings patches and to determine the relationship between organic matter and the metal distribution in the material on the shores.

An increase in concentrations of zinc in the water of Decant Pond was noted in spring and autumn (changes from a high of 7 mg/l to 1 mg/l during the summer), with a concurrent slight increase in the concentration in Mud Lake water (changes from a high of 0.2 to 0.04 during the summer). The fine precipitates on the bottom of Decant Pond are covered with a layer of lime. At present metals contained in the material are not mobilized given the anoxic reducing and alkaline conditions. These are to be maintained in the future with the establishment of a wetland. Biological Polishing processes were identified in Decant Pond. The chemical, physical and biological interactions between the sediments, surface water and biota in this system require further delineation prior to the implementation of appropriate close-Out measures.

In general, the water quality and the sediment characteristics of the Mud Lake system (Mud Lake, its east and west arm) have not been affected by the discharges from Decant Pond. The system consists of sediments rich in organic matter and very dense wetland/muskeg vegetation.

The water characteristics in Mill Pond showed large variations during the season but because run-off from the mine site is presently entering the pond, the behaviour of Mill Pond will likely change after the buildings on site have been dismantled and the surface is reclaimed. Experiments to improve the quality of the water leaving Mill Pond produced promising results and await evaluation of overwintering and growth in 1987. Water leaves Mill Pond mainly during spring run-off through a ravine (Mill Pond run-off). A retention dam (Dave's Dam) was built to retain some of the spring run-off,as the water quality in the ravine indicated decreasing metal concentrations from spring to autumn. It is anticipated that a wetland will develop behind the dam, which will provide metal binding sites, i.e. polishing capacity for run-off water.

Boomerang Lake is a completely mixed shallow lake which receives run-off from Mill Pond, the tailings, and some spill areas. The pH of the lake is 4.3 $\pm$ 0.26, with an electrical conductivity around 325 umhos/cm with conditions resembling those of an acidic peat bog. The phytoplankton community was found to be typical of Shield lakes which have been acidified due to acid precipitation, despite high (8.3 ± mg/l) concentrations of zinc in the water. Other metals do not appear to be elevated in Boomerang Lake. Biological Polishing processes were identified in the lake and should be promoted to assist in the removal of zinc from the water column. Measures have been implemented which are intended to reduce contaminant loads to the lake in the future. They consist of curtailing run-off from the Mill site, from the spill areas and from the tailings by retention of water, (Harold's Dam) and diversion (Spill area 2), or reduction of water **flow** (tailings dams). Hydrogeological investigations are required to determine the water regime of the entire waste management area for the correct placement of ecologically engineered wetlands.

The water quality of Confederation Lake at the discharge points (Boomerang Lake, Mud Lake west arm, and mine site beach) is not at all degraded. The water parameters evaluated are the concentrations of copper, lead, iron and zinc, which metals were monitored during operation of the mine. To evaluate water quality in broader environmental terms, the concentrations of arsenic, cadmium, chromium, mercury, molybdenum, nickel and selenium have been assessed. Furthermore, the concentrations of essential elements (Al, Ca, K, Mg, Mn, Na, P and S) have been evaluated, since the proportions of these elements can vary due to acid drainage. In Confederation Lake, at the discharge points, and along the shores of the waste management areas, all the elements were present within concentration ranges reported in the literature for freshwater. Environmentally sensitive species of phytoplankton were consistently present in samples at the discharge points, confirming the absence of any detrimental effects of the discharge. However, the parameters evaluated were consistently altered in those locations of the waste management area (Decant Pond, Mill Pond and surface seepage from the tailings) which are the focus of ongoing experiments.

The objectives of the ongoing Ecological Engineering experiments are briefly : 1) to promote those processes which are known to prevent conditions that lead to acid drainage, and 2) to improve water quality in those locations where acid drainage will persist for a considerable period of time. Reducing conditions and organic matter production are the key ingredients of self-sustaining treatment systems. The first step is to develop methods for the establishment of wetlands. Various cattail transplant methods have been tested and the resultant growth indicated promising results in Mill Pond and Decant Pond. Amendments (sawdust) to Mill Pond water resulted in consistent adsorption of metals and improved pH values of the water. Biological polishing processes have also been identified for Boomerang Lake and Decant Pond. Dense mats of periphytic algae indicated concentration factors of metals (conc. in biomass conc. in water) ranging from 190,000 to 700, suggesting active uptake of the metals zinc, iron and copper by the biomass from the water.

In summary, the thorough assessment of the waste management area of the South Bay Mine site and the immediate vicinity of Confederation Lake, leads to the conclusion that no immediate environmental degradation is evident. The focus of the ongoing experiments is therefore the prevention of problems which are anticipated in the long term. After the evaluation of the over-wintering and growth results in 1987, an appraisal of the various components necessary to develop ecologically engineered wetlands, the implementation of measures to enhance the biological polishing processes which have been identified, the delineation of the hydrogeological regime and, finally, the confirmation of the trends indicative of the long term behaviour of the waste management area described in this report, it will be possible to proceed with the next step towards a pilot demonstration of self-maintaining close-out measures.

ACKNOWLEDGEMENTS

It requires some measure of courage to attempt to develop a novel, environmentally sound and, last but by no means least, an economic method for the close-out of base metal mining operations. Just as that word needs assistance to convey the kind of support that is essential for true success, the encouragement we at Boojum Research **Limited** received from a number of people made this research project possible and promising. First and foremost, I wish to thank Godfrey MacDonald for his interest in Boojum's ideas, and Glenn Mallory of BP Selco for his support, patience and confidence throughout the development of the project. The help that Boojum received on site from Dave Kesick and Bob Brisco was invaluable and, on many occasions, the tasks at hand could not have been completed without their assistance.

Many aspects of the field work and data assembly were tedious, painstaking exercises, and we are indebted to our summer students, Maxine Shumlick, Rene Chan and Richard Pearce, for their perseverance and stictuitiveness. Finally, I am indebted to Jennifer Reuben who, with quiet determination, assisted with the completion of this report.

ABANDONMENT PLAN FOR SOUTH BAY MINES

BP RESOURCES, SELCO DIVISION

PHASE 1

DETAILED SITE ASSESSMENT AND ABANDONMENT APPROACH

1. BACKGROUND AND INTRODUCTION

The economic metals of the South Bay mine were copper and zinc with some fraction of silver. The operations at South Bay ceased in May 1981 after a ten year life span of the mine. Decommissioning activities with respect to mine closure have been completed. Steps are being taken to remove all above-ground structures by the end of 1987. The environmental aspects of the waste management area have been carefully considered and several options were assessed.

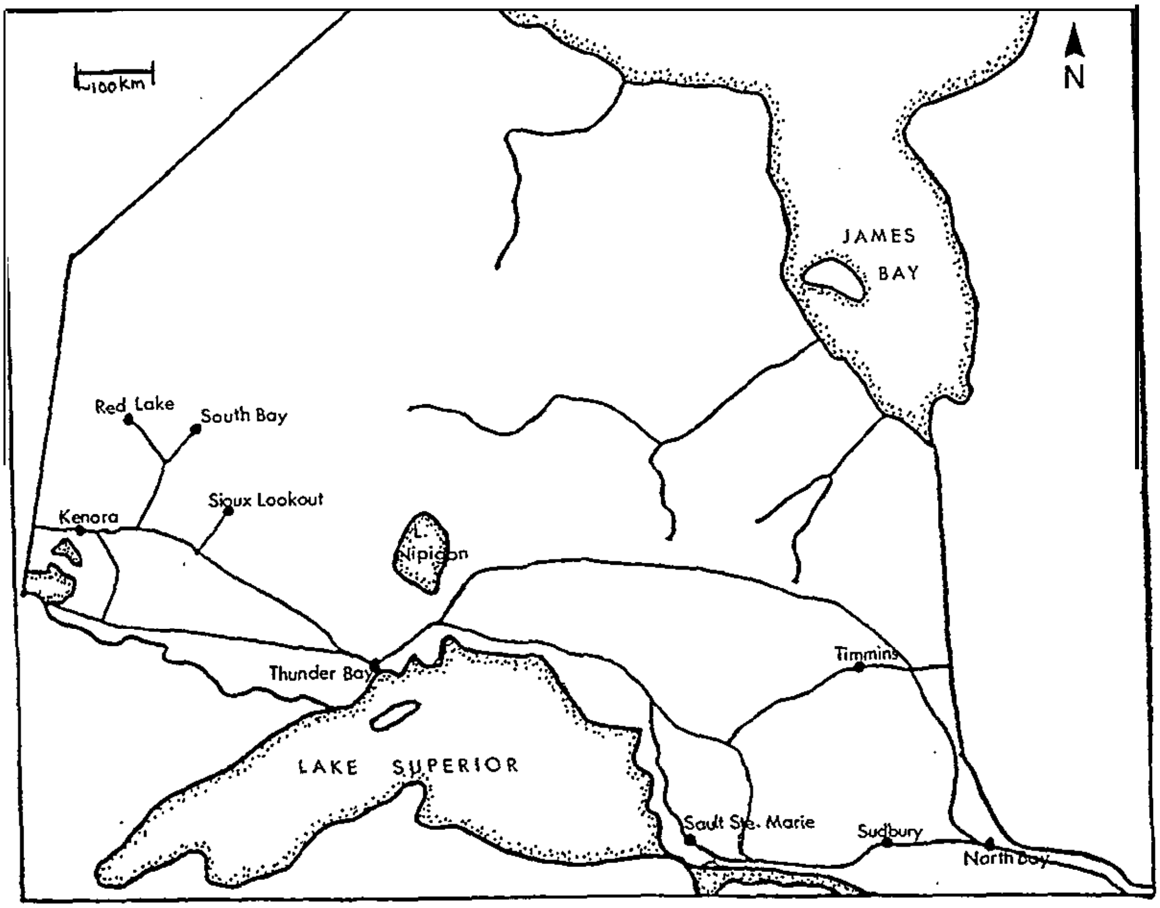
Perpetual liming of the acidic drainage present on the site has been evaluated as one of the options available for abandonment purposes. This option was considered by BP however, to be a short-term interim solution. BP has, therefore, obtained approval from the Ministry of Environment to engage in a research program to test a novel approach to the abandonment of acid generating waste management areas. In this connection, Boojum Research Limited has been retained to carry out the research necessary to obtain the required information and then to implement those measures indicated by their investigation. In this manner, it is hoped that the abandonment of South Bay Mines land will be accomplished in an environmentally acceptable fashion.

This report represents the first phase of this research work, referred to as Ecological Engineering and Biological Polishing. In the first section of the report, a detailed description of the environmental conditions of the waste management area is presented. Emphasis is placed on those elements which have been monitored in effluents during operation of the mine and mill. A second section addresses the potential environmental effects of the waste management area. A third and final section presents the results of experiments which are pertinent to close-out measures and the environmental recovery and or reclamation of the site.

2. SITE DESCRIPTION

2.1 Characteristics of the area

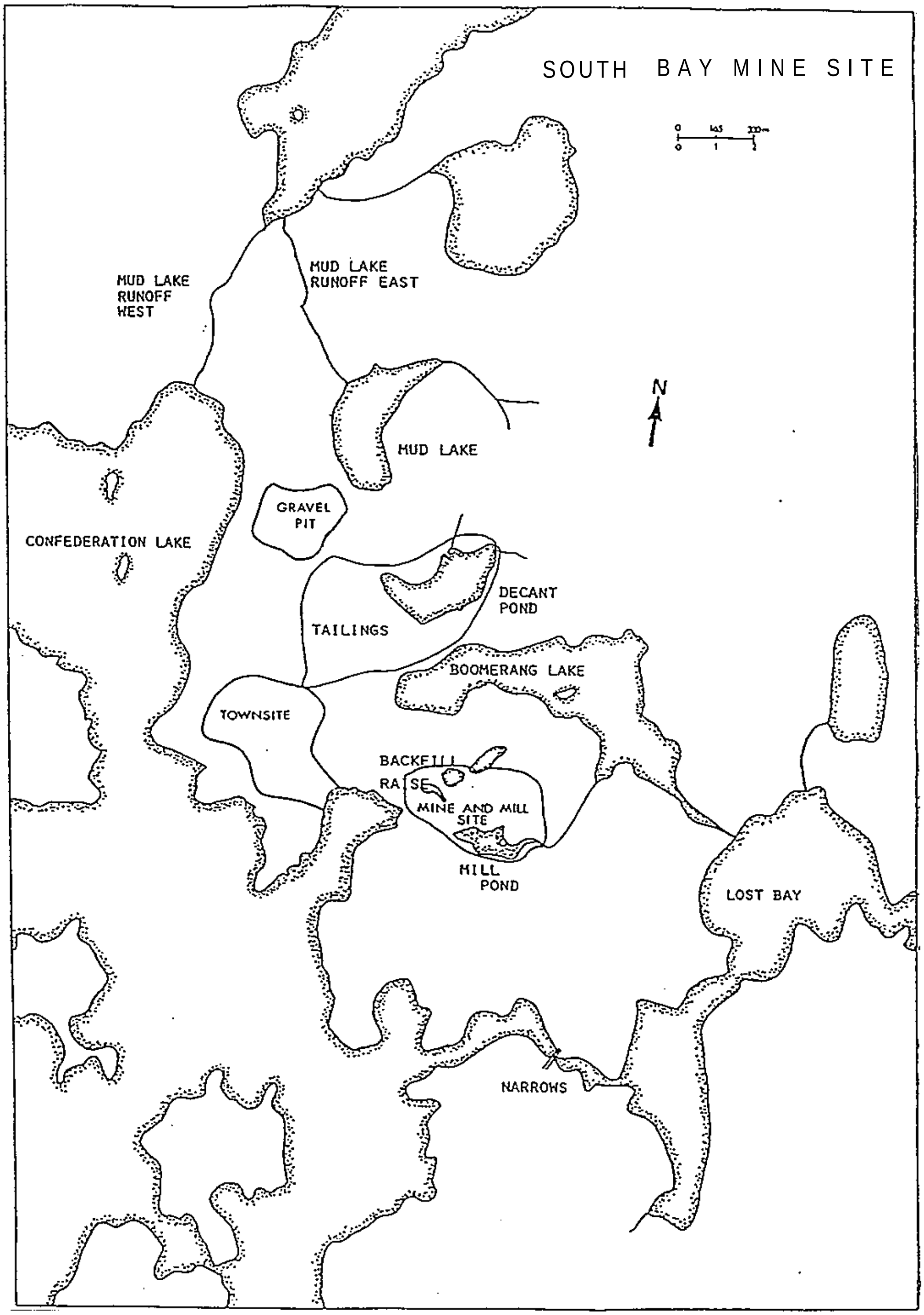
The biogeographical characteristics of the area in which South Bay is located are typical for Northern Ontario (Map 1, Page 3). The mine site is close to Confederation Lake which is part of the English River drainage basin. The Northern Coniferous forest region in this area is dominated by spruce, jack-pine and tamarack. The soil of this area of the Precambrian Shield is classified as a humo-ferric Podzol with a dominantly rolling to hilly topography, displaying significant stony and lithic phases. The frequency of peatlands and wetlands is evaluated as medium (Fahlgren, 1985).



Map 1. Location of South Bay mine site in Northwestern Ontario.

2.2 Characteristics of the mine site

Eighty-five km northeast of Ear Falls the access road ends at South Bay (Lat: 51° 08m Long: 92 ° 40 m), the former mine and mill site which is in close proximity to the former townsite and the tailings. The entire area covers approximately 73 ha. An overview of the mine site and all associated names and reference points are given in Map 2 (Page 4).



Map 2. South Bay Mine Site overview and reference points.

The tailings cover a total area of 27 ha, of which 14 ha axe dry and revegetated, and 13 ha are covered by a pond referred to as Decant Pond. Tailings dams close to Boomerang Lake were constructed in lifts and concrete was poured directly on the bedrock. These dams are laterally supported with waste rock and gravel. Three other dams containing the tailings on the north, north-east and north-south boundaries are constructed of waste rock and gravel.

The tailings area was reclaimed in 1982. The total tailings tonnage discharged into the containment is estimated at about 835,000 tons. Approximately 1.4 million tons of ore were processed at the site during its 10 year life, and about 0.5 million tons of coarse tailings were used as backfill i.e. they were returned to the underground workings of the mine.

The gravel pit of the mine site is located to the north-east of the tailings and there is a shallow lake slightly farther north, which is referred to as Mud Lake. The former townsite was on the south-east end of the tailings. The southern perimeter of the tailings is bordered by the east tip of Boomerang Lake which drains into Lost Bay, a waterbody connected to Confederation Lake through the Narrows.

Mine and mill together cover an approximate area of 15 ha, which includes a small pond collecting run-off from the mine site, and a revegetated waste rock area. The pond is referred to as Mill Pond. It appears to drain toward Boomerang Lake through a swampy ravine which is about 300 to 400 m long and is named Mill Pond run-off.

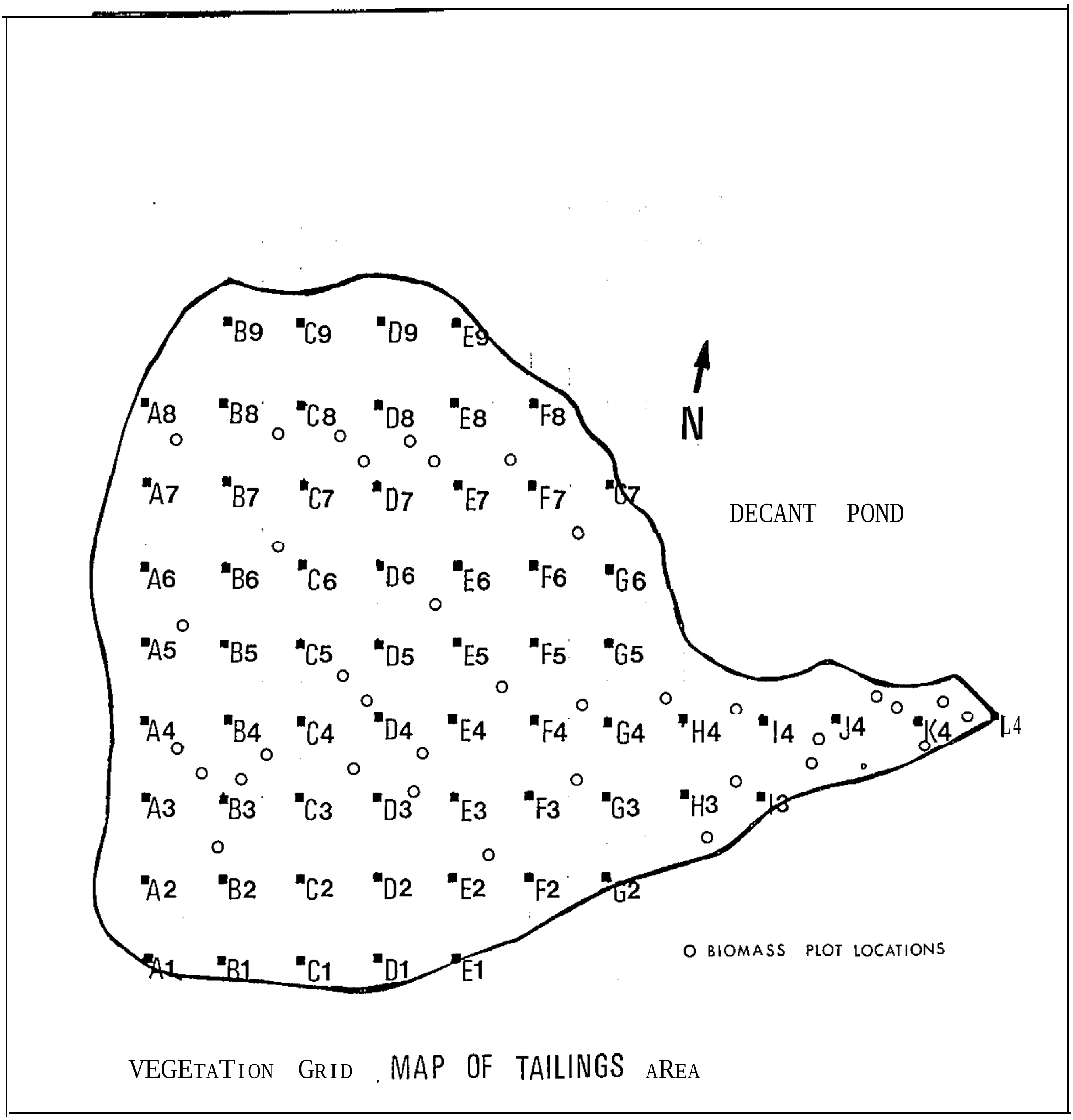
Drainage from a small tailings spill collects in a small puddle close to the Backfill Raise area on the west side of the mine shaft. This puddle dries out nearly completely during the summer months and drains through fill material towards Confederation Lake. The buildings, mine shaft, mill and warehouse still present on the site are scheduled for dismantling in 1987.

3. METHODS

3.1 Field investigations

Waterbodies on the site were investigated with limnological methods. Depth profiles were determined with a secchi disk, and sediment samples were collected with an Eckman grab. Water samples were collected on the surface (0.5 m). Phytoplankton samples were integrated at those sampling locations which had a depth of >2 m with a tube approximately 2.5 m long. In more shallow locations the phytoplankton was represented by a grab sample.

Terrestrial areas were mapped, estimating area1 extent by footsteps or laying out a 50 m grid (Schematic 1, Page 7). Surface characteristics which are relevant in relation to environmental aspects of the site were described, and grab samples for analysis were collected in selected locations. Vascular and non-vascular plants which frequently occurred in the investigated areas were collected for identification.

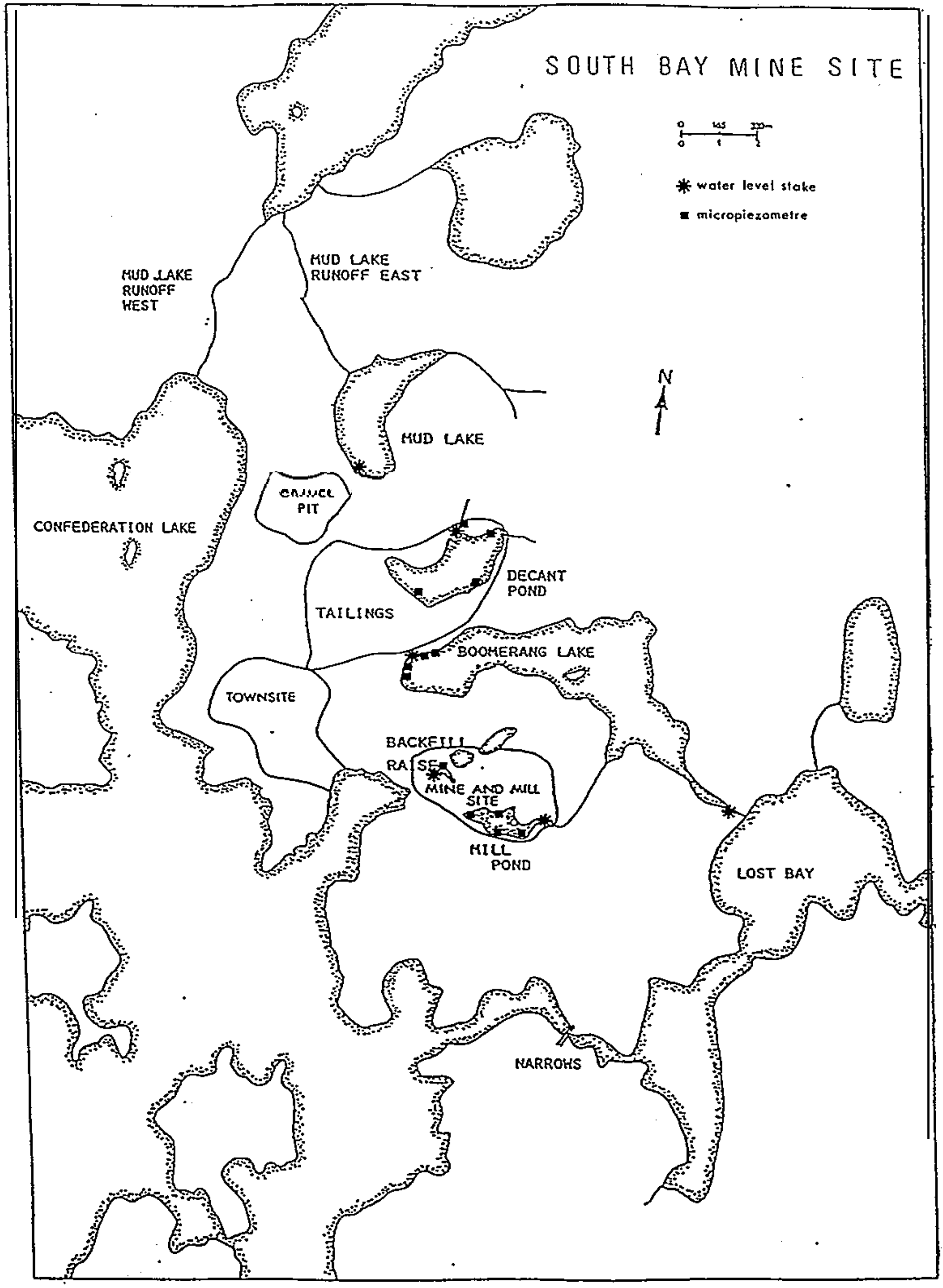


Schematic 1. Reference points and locations of fertilization plots-on tailings

Electrical conductivity and pH were measured in-situ in all water bodies and in soil / tailings slurries with pH meters (IL PortoMatic 175 and Corning pH 130) and conductivity meters (Hach Model and YSI Model 33, S-C-T). The instruments were calibrated with buffers (pH 4, 7 and 10) and standard solutions (saturated KCl) at regular intervals, before and after each set of readings.

Preliminary hydrological data were collected with micropiezometers, modified after Lee and Cherry (1978), consisting of 1.5 cm diameter PVC tubing fastened to a 1" X 1" stake, were used to measure piezometric levels in bottom sediments. The bottom of the tube was covered by a screen and placed about 30 cm into the sediment. The tops of the tubes were folded over. A reading for such a micropiezometer consists of the difference between the water level in the water body and that in the tube, recorded in cm. Water-level stakes with markings were placed in several locations. They were read directly at the stakes throughout the summer season. The locations of the water-level stakes and the micropiezometers are given in Map 3 (Page 9).

Tailings vegetation was mapped in detail based on a grid given in Schematic 1 (Page 7). The root zone was investigated by excavating pits with a shovel. The depth of the overburden cover, root penetration and visible tailings oxidation state were recorded and measured in the pits with a ruler in cm.



Map 3. Locations of micropiezometers and water level stakes

Fertilization plots were set up in 0.25 m^2 plots with a one time application of standard fertilizer (N 21,P 7,K 7) of 0.025 kg/m^2. The locations of the plots are given in Schematic 1 (Page 7). Biomass of vegetation cover was determined by harvesting in May and at the end of July, i.e. at both the beginning and the end of the growing season. All above ground vegetation was clipped by hand with scissors. The biomass was air-dried and weighed to the nearest gram. Vascular plants and mosses which formed a significant part of the species composition were collected for identification. Mosses were identified by C. Manville and vascular plants by M. Olaveson. Moss specimens were deposited at the National Museum in Ottawa. Vascular plants are tentatively identified at the species level.

Phytoplankton samples were collected using a weighted tubing sampler to obtain integrated samples for the deep locations in Boomerang and Confederation Lake and dip samples were obtained for shallow sampling locations. One litre samples were preserved with Lugol's fixative and stored at room temperature until examined.

The sample was allowed to settle in a settling chamber for at least 5 days to concentrate the algae. Approximately 850 to 900 ml of water was siphoned off and discarded. The remaining sample was resuspended and then allowed to settle for 2 days for further concentration resulting in a final volume of 20 mls. Aliquots of the samples were used for identification and enumeration.

Periphyton was identified unpreserved with a Wild M40 Inverted.

Microscope equipped with phase contrast objectives (10X, 40X, 100X).

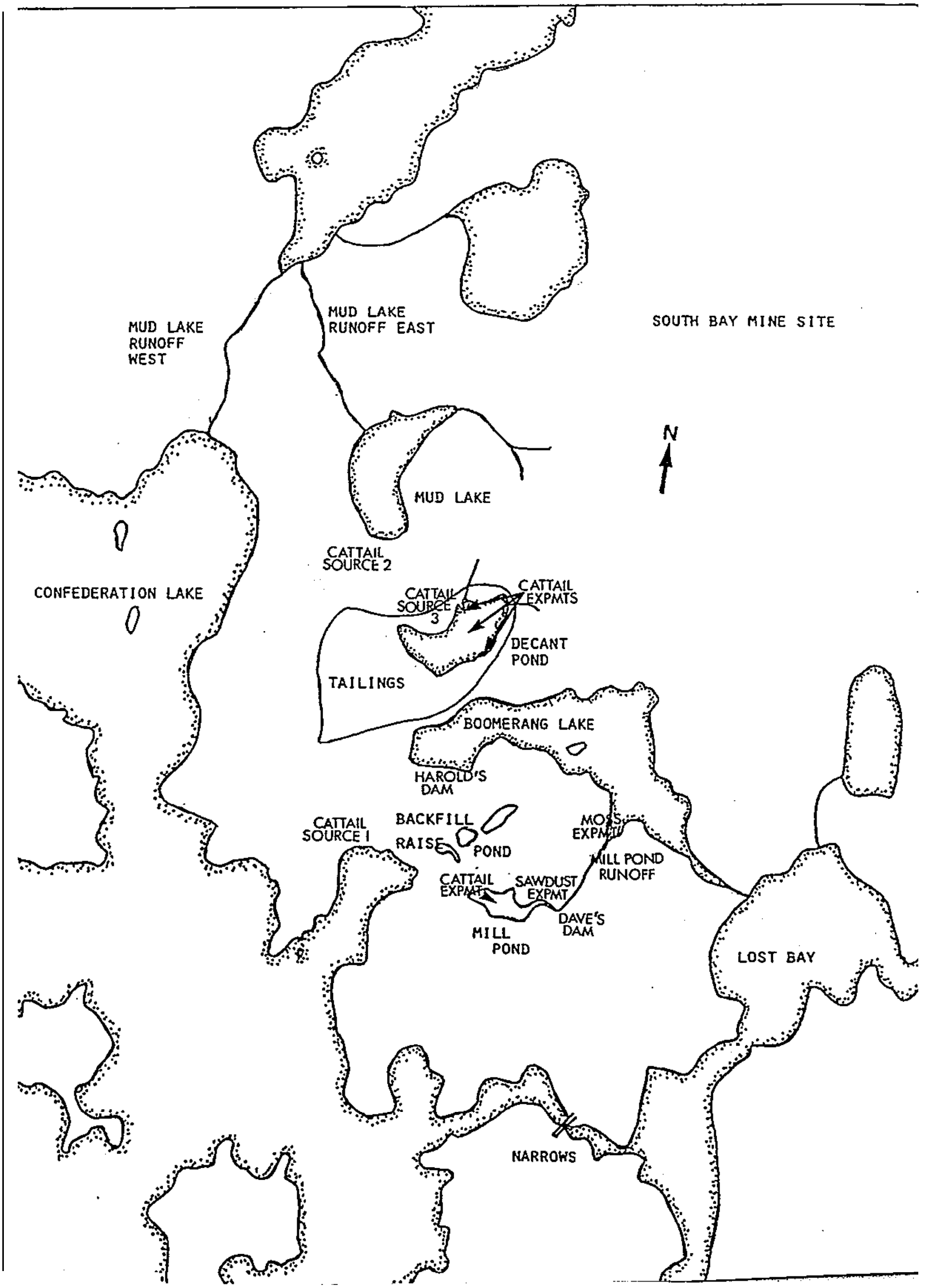
3.2 Experimental methods

Cattails transplants: Three methods of transplanting cattails from local populations in the area were tested. Mechanical transplanting was carried out by a front-end loader. This resulted in sections of dense cattail roots/rhizomes of about 1.5 m long and 0.5 m wide (Plate 1, below). These were placed along the shoreline of Mill Pond and Decant Pond.

Plate 1. Mechanically transplanted cattails (Decant Pond)

The location of the experiments is given in Map 4 (Page 13). Hand transplanting was carried out by planting individual cattails with a shovel in groups of 6 to 10 along the shores of the same water bodies (Plate 2, below). Hydroponic transplanting was tested by two means. Toot/rhizome stocks were fastened in fishnetting which was suspended on ropes about 0.5 t 1 m below the surface of the water (Plate 3, Page 14). Individual plants were planted in racks (Plated 4, Page 14). The roots/rhizomes either embedded in sphagnum moss or suspended in the netting directly in the water.

Plate 2. Hand transplanted cattails (Decant Pond)



Map 4. Locations of various experiments in South Bay Mine Site

Plate 3: Hydroponic cattails suspended by fishnetting on ropes.

Plate 4: Hydroponic Cattails Suspended in Racks.

Sawdust Experiment: Approximately 4 m^3 of fresh sawdust was placed in the discharge channel of Mill Pond, after all precipitate from previous lime treatments at that location had been removed by excavation.

Water sample analysis: All water samples were filtered through 0.45 um filter and acidified with conc. nitric acid within 24 hrs after sampling. Acidity was determined by titration with NaOH following ASTM standard method. For determination of acidity, unfiltered unacidified samples were collected. All chemical analyses were carried out by Assayers Ontario Ltd. by ICP.

Control samples were obtained by filtering (0.45 um) and acidifying the rinse water used on site at the end of the sampling period. The filtration apparatus was acid washed between each sampling period. Those control samples give a reference point for potential contamination during the filtration procedure.

The solid samples were dried at 100 °C and digested by wet oxidation with hydrofluoric/hydrochloric acid. The solution was brought to dry point and redigested in HF/HCl and nitric/perchloric acid. Loss on Ignition values were determined by ashing at 1000 °C in a muffle oven.

4. RESULTS

4.1 Waste site descriptions

4.1.1 Tailings

Tailings deposition and reclamation history : The last layer of tailings material which was deposited during operation consisted of slimes, estimated to have a grain size of about 80% passing - 15 um. These slimes were point discharged from 1978 at the north-east end of the tailings area. Before the tailings were required as backfill material, previous discharge points were located at the south side of the tailings. The majority of the mixed tailings (coarse and slimes) would therefore be deposited in the southern portion of the dry section of the tailings, whereas the north-eastern portion would contain more slimes.

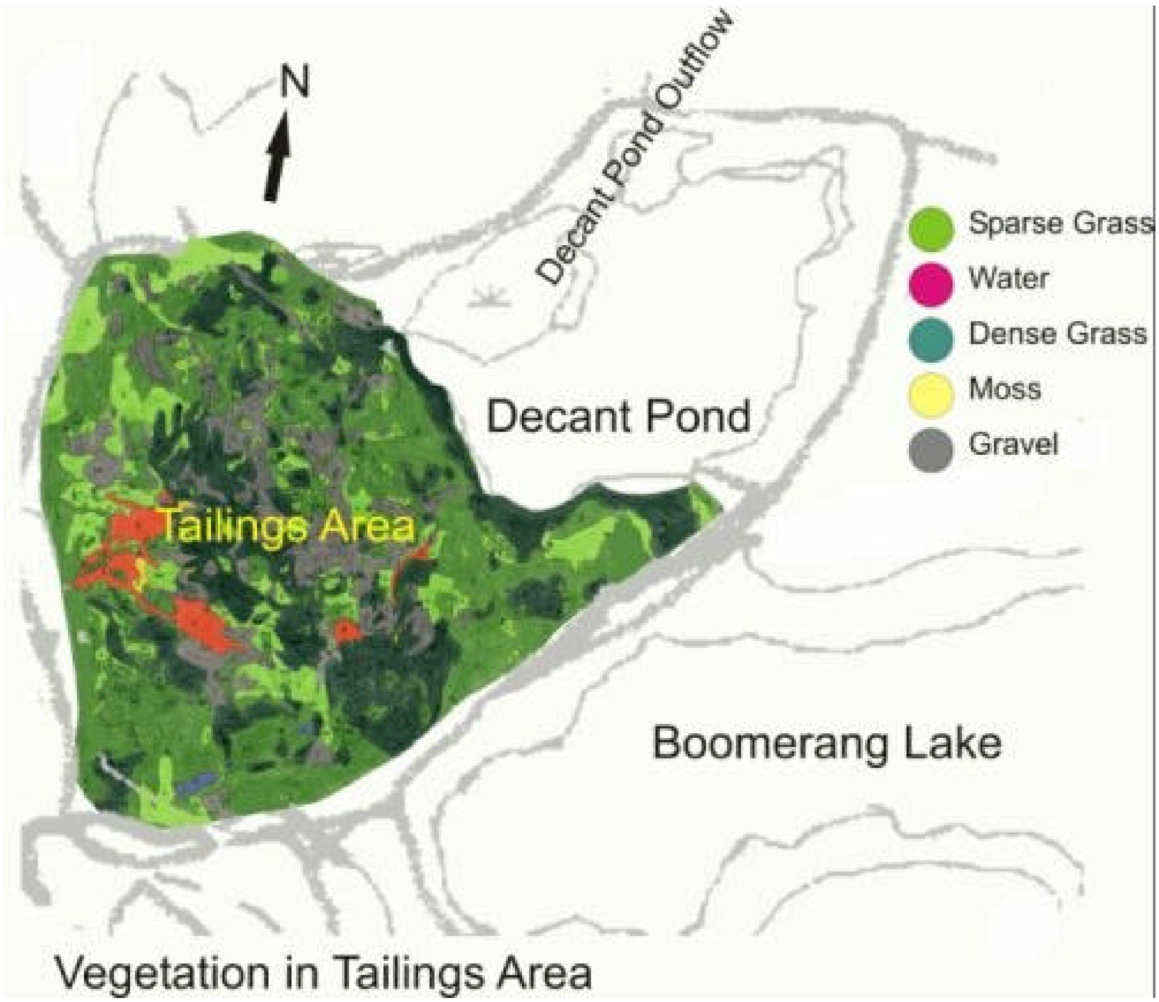
The overflow from the tailings area collected in the appropriately termed, Decant Pond, which discharged into Mud Lake. During operation no lime treatment was required as the flotation tailings were discharged at pH 9 to 10. Since 1981, the time of mine closure, Decant Pond was limed twice every year, in spring and fall, receiving about one third of a truck load or about 7.5 tons of lime.

Decant Pond was not limed in 1986 to assess the behaviour in the absence of liming.

The reclamation of the dry tailings area was carried out in 1982. The tailings were covered with approximately 30 to 50 cm of overburden from the gravel pit on site (Map 3, Page 9). This surface was fertilized, brillion seeded with a seed mixture consisting of birdsfoot trefoil and tall-fescue and hydromulched. The vegetation cover developed without any further amendments.

The state of vegetation cover in 1986: The characteristics of the surface of the tailings were evaluated to determine whether any beneficial effects could be noted which would reduce acid generation in the tailings. The areas of different surface types are outlined in Map 5 (Page 18). Several waterlogged areas (red) are due to poor drainage during snow-melt run-off and precipitation events. Subsequently these sections have no vegetation cover. All areas with gravel (grey) are also free of vegetation. A third vegetation free surface type, on a small section of the tailings referred to as "straw" (blue), had a dense cover of dead birdsfoot trefoil inhibiting the growth of other vegetations.

Three density related quantifications were made with respect to the vegetated surface. Background grass cover (Plate 5, Page 19, coded green on Map 5, Page 18), is a medium dense vegetation. This type appears to be the predominant type of vegetation cover which has developed since reclamation. In the center of the tailings area a dense grass cover (Plate 6, Page 19, coded dark green on Map 5, Page 18), is present, which also occurs close to the beach of Decant Pond. Sparse vegetation cover (Plate 7, Page 20, coded light green on Map



Map 5. Vegetation map of tailings area in South Bay

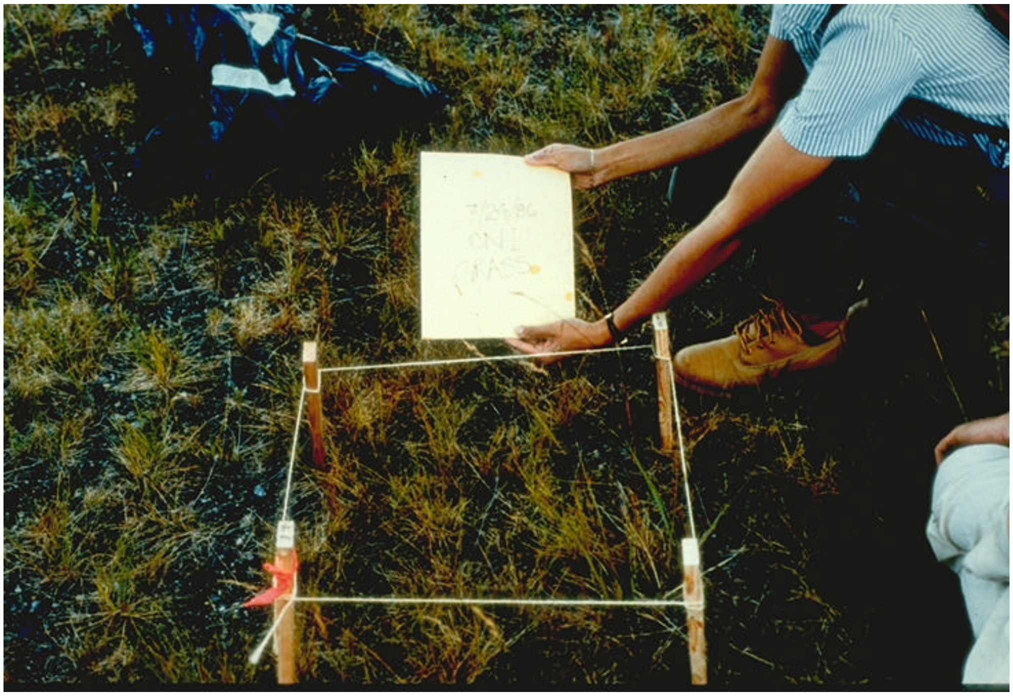


Plate 5: Background grass cover.

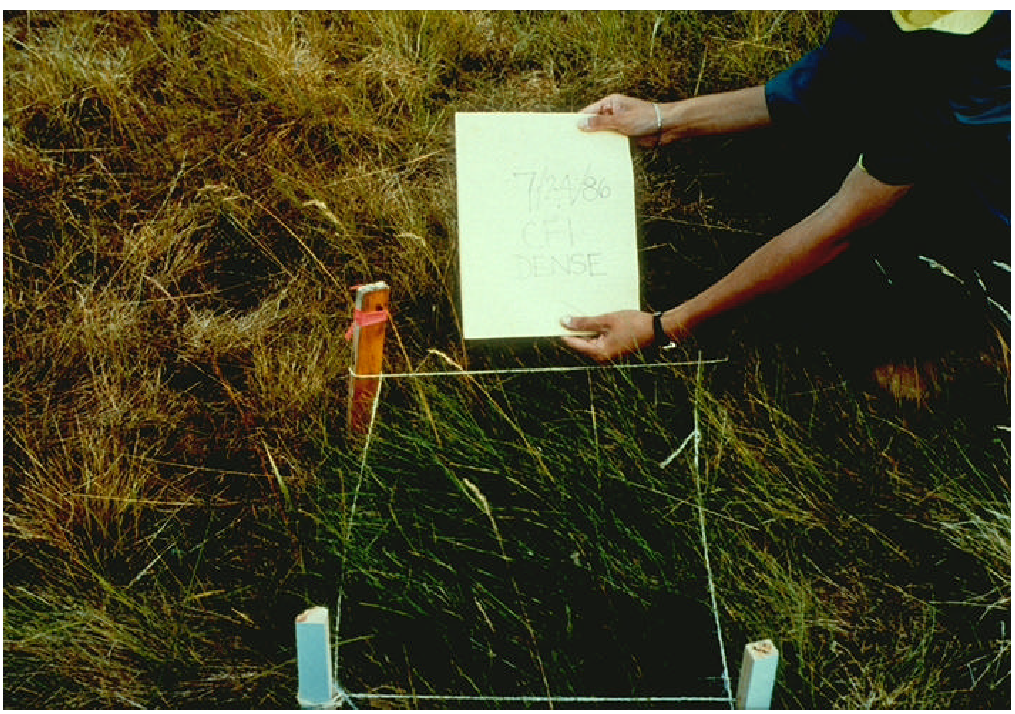


Plate 6: Dense grass cover.

Plate 7: An example of sparse vegetation cover.

5, Page 18) has a patchy distribution on the tailings.

A rough assessment of the surface topography was carried out by measuring depression and heights. Areas with more exposure could be expected to experience various degree of draught stress, a frequent growth limiting factor on the tailings. However, it was possible to connect the different vegetation densities to those parameters.

An investigation of the stratification underlying the different vegetation and surface-cover types was carried out. It was hope to determine if below-ground factors could account for differences noted on the surface. In Table 1 (Page 21), the observation on the stratification found in 4 to 6 pits below each surface type are presented. The parameters and their variability are similar for each surface cover type. Only one definite difference was evident for the stratification below the gravel surface. The fill layer here is thinner compared to the other surface types. Gravel was differentiated from fill by the more coarse gravel or pebbles with a diameter > 3 cm, whereas fill was of finer sandy material.

SURFACE COVER TYPE	SAMPLE #	THICKNESS OF FLLL		DEPTH TO OXIDIZED LAYER		DEPTH TO TAILINGS		ROOT PENETRATION		THICKNESS OF ORGANIC LAYER	
		X	s	X	s	X	s	X	s	X	s
SPARSE GRASS	n=5	26.4	7.3	28.4	9.2	29.6	7.0	15.6	3.8	0.16	0.09
BACKGROUND GRASS	n=5	31.8	11.5	32.3	11.4	33.9	10.1	14.4	8.2	0.48	0.33
DENSE GRASS	n=4	43.8	15.8	44.5	15.5	45.0	16.0	22.0	2.4	0.73	0.86
MOSS	n=5	31.3	11.3	31.8	10.9	34.3	15.2	6.1	4.0	0.36	0.35
STRAW	n=4	38.1	11.9	26.4	19.4	42.0	7.0	3.0	4.8	0.15	0.1
GRAVEL	n=6	10.5	12.8	10.5	12.8	17.6	12.5	0	0	0	0

Legend: units in cm. n = # of samples x = mean value:
s = standard error

Table 1. Tailings stratification characteristics under various surface cover types

In general, for all surface types, the thickness of the fill is around 30 to 40 cm. The oxidation layer is 2 to 3 cm below the base of the fill. Root penetration was found to be the deepest (mean 22 cm $\pm$ 2.4 cm) in the dense vegetation cover, compared to background grass cover (14.4 $\pm$ 8.2 cm). The dense vegetation type is associated with the thickest fill layer, and one can therefore argue that growth is better on a thicker cover of fill.

The depth of fill and the density of vegetation cover however, showed little relationship with the depth at which the tailings were found to be acidic. The pH in the tailings was consistently below 3.5 below the fill (Table 2, below).

SURFACE COVER TYPE	SAMPLE #	pH					TEMP. - C		
		SURFACE		FILL		TAIL.	SURFACE	TAILINGS	DIFFERENCE
		X	s	X	s	X	X	X	X
SPARSE GRASS	n=5	6.6	0.8	6.0	1.5	<3.5	28.8	14.9	13.9
BACKGROUND GRASS	n=5	6.8	0.5	6.5	0.8	<3.5	23.4	11.9	11.5
DENSE GRASS	n=4	6.8	0.4	6.6	0.5	<3.5	19.3	12.3	7.0
MOSS	n=5	5.7	0.8	5.8	0.6	<3.5	24.4	14	10.4
STRAW	n=4	6.4	0.6	6.9	0.3	<3.5	20.6	11.5	9.1
GRAVEL	n=6	4.1	0.6	-	-	<3.5	27.9	15.5	12.4

Legend: n = # of samples **x** = mean value s = standard error

Table 2. Surface types and corresponding pH and temperature in various layers of the pits.

Measurements were taken in the various layers of the pits and were generally in the "neutral" range with pH 5.8 to 6.9. The oxidized layer of tailings (0.2 to 0.5 cm), , which is located directly beneath the fill layer (within 1 to 2 cm) for all surface-cover types, does not suggest that there is any obvious reduction in the depth at which acid is generated in the tailings.

The surface of all cover types, with the exception of the gravel (pH 4.1) is close to neutral, ranging in pH values from 5.7 to 6.8. This pH range is similar to that for the fill material underneath. It is likely that the neutral pH on the surface and in the fill material is a reflection of the characteristics of the fill with some neutralizing capacity.

The mosses identified on the tailings are generally species which occur on reclaimed tailings. <u>Bryum algovicium</u> and <u>Funaria hygrometrica</u> and <u>Ceratodon purpureus</u> are weedy species previously identified on tailings (Kalin, 1986). Their occurrence, due to their calciphylic nature, indicate the presence of neutral material in the fill.

Acidophilic mosses on the other hand were identified in water logged areas of the tailings or in depressions close to the beaches of Decant Pond. These species are <u>Leptobryum pyriforme</u> and <u>Depanocaldus fluitans</u>. Both species are consistently associated with acidic tailings.

From the above-mentioned observations on the vegetation cover types and the underlaying strata, ameliorative effects on the acid generation beneath the fill cover can only be expected indirectly.

A reduction in the amount of precipitation penetrating the tailings is likely to occur due to the vegetation cover. The fill material, on the other hand, has a higher porosity and permeability compared to the tailings. This might counteract the reduction in filtration caused by the vegetation. A vegetation cover could also reduce the temperature in the tailings, which would be beneficial in reducing microbial activity. Temperature differences on the surface are evident but these differences do not appear to affect the temperature of the tailings layer below the fill (Table 2, Page 22).

In the final analysis, the tailings surface is heterogeneous, consisting of areas covered with a neutral fill with various degrees of vegetation development. The vegetation type and the fill cover do not affect the depth at which the tailings are acidic. The tailings, 2 to 3 cm below the fill, are consistently acidic. Only in the gravel covered areas is the pH lower, closer to the surface.

The various vegetation characteristics on the fill will change in the long term and the surface will continue to display a heterogeneous character. Some indication of the change is given by the composition of vascular species dominant on the tailings . This species composition was determined based on the collection of vascular plants which were frequently found on the tailings. Vascular plants which were identified consisted of a combination of sedges (Carex aquatilis cf.), Wild rye, Fuzzy wild rye, Orchard grass and Quack grass (Elymus sp., Agropyron repens cf., and Dactylus glomerata), Foxtail barley (Hordem jubatum), Smooth brome grass (Bromus inermis), Woolgrass or Bog cotton (Scirpus cyperinus), Birdsfoot trefoil and Alsike clover (Lotus coniculatus and Trifolium hybridum). All these species have one characteristic in common -they are typically found in wasteland habitats as early colonizers. It is interesting to note that birdsfoot trefoil appears to be more persistent than tall fescue, which was not found as a dominant species although both species were introduced with the seed mixture used for reclamation.

The results of the fertilization experiments clearly reflect the nutrient limitations which are typical for waste lands. Fertilizer (N21-P7-K7) was applied to the three grass cover types (sparse, background and dense) and the resultant above-ground bio-mass was evaluated. The location of the fertilizer plots is given in Schematic 1 (Page 7), and the results are summarized in Table 3 (Page 26). The biomass produced without fertilization is negligible (15g/m^2) for the sparse cover, and small(53-57g/m^2) for the background grass and dense vegetation cover.

Mean biomass in grams/square metre (standard deviation)

Date of Harvest	Description	SPARSE	GRASS	DENSE
5/24/86	Initial Harvest*	68.6 (23.6)	1176.4 (67.5)	1346.6 (116.9)
7/24/86	Final Harvest	80.7 (37.6)	230.1 (3.6)	1404.1 (88.1)
	Increase in Biomass	+15.1	+53.6	+57.4
7/24/86	Effect of Fertilizer	+83.9	-11.4	+110.33
7/24/86	H-Non-Fertilized	4.3 (1.1)	48.5 (63.7)	49.1 (19.2)
	H-Fertilized	107.0 (65.5)	87.7 (49.5)	143.8 (49.6)
	Fertilizer with Harvest	+102.7	+39.3	• 94.7

Lggend: sample size (N)= 2 to 3; * N=6; H- harvested.
One Time Application of Fertilizer (21-7-7) on 5/24/86
6.25 grams per (0.25x0.25)square metre

Table 3. Biomass results from fertilization experiment on the three grass cover types.

When these covers were fertilized, either with the original vegetation in place or after all biomass was removed, the increase was most consistent for the sparse and dense cover. The net increase in above-ground biomass (g/m^2) due to application of fertilizer, was about the same for the dense and sparse cover types, ranging from 84 to $110 g/m^2$. For the background cover, the values obtained are extremely varied, and therefore, increases in biomass due to fertilizer are subject to equal variation resulting in some negative values

(-11.4) (Mean Biomass increase of 2 months subtracted from Mean Biomass value with fertilizer). Essentially, the increases in biomass due to fertilization indicate that the same effect is obtained regardless of the vegetation cover type and the removal of biomass prior to fertilization. An increase in biomass on the tailings could therefore be produced by fertilization.

However, given the stratification of the material underneath the vegetation cover, (as shown in detail in Tables 1, Page 21 and 2, Page 22), it is unlikely that an increased biomass on the fill material would significantly affect the acid-generating behaviour of the tailings underneath the fill.

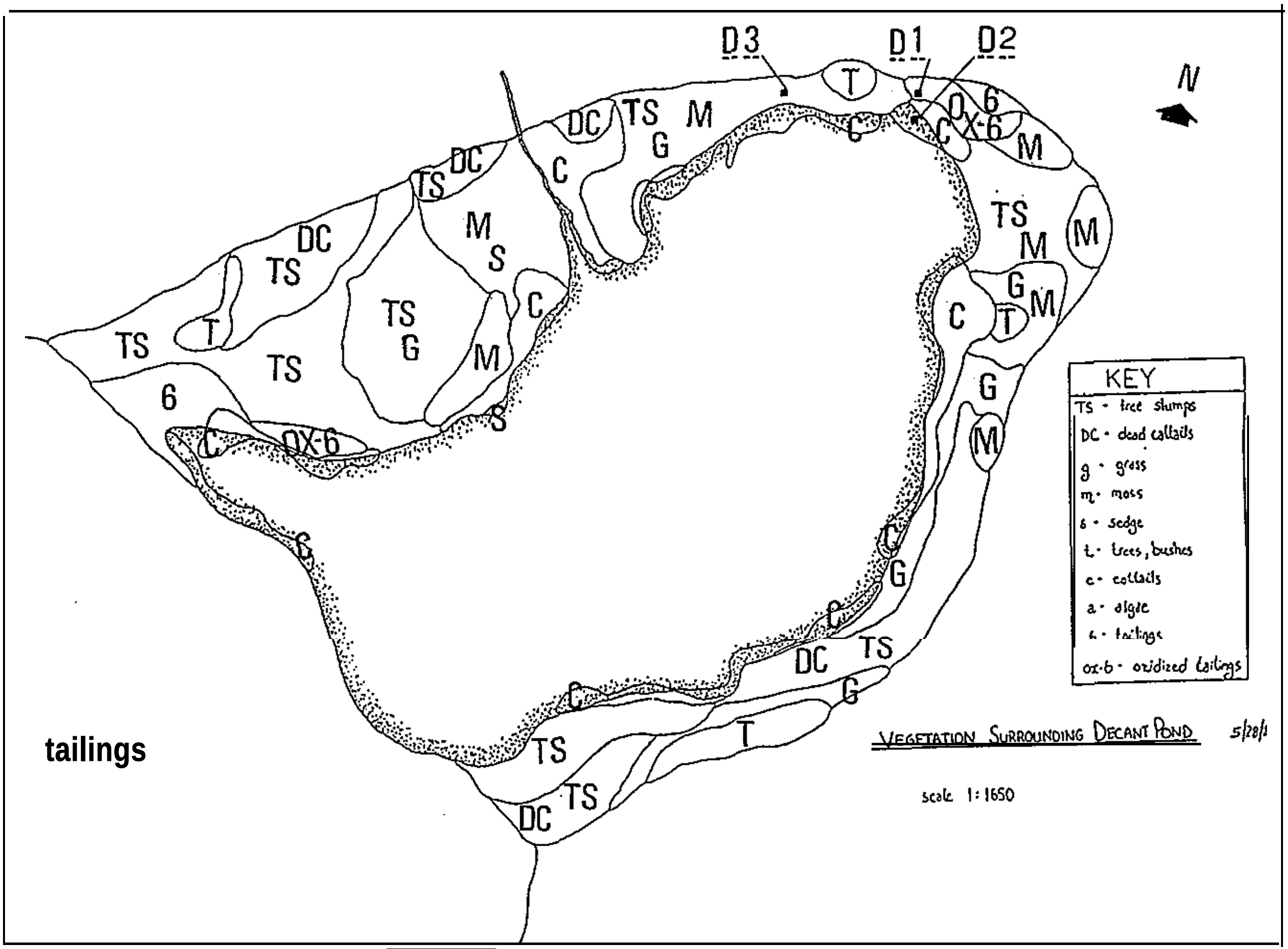
Fertilization would result in increased root penetration and this should be carefully evaluated with respect to the long-term implications for the tailings. The effects of roots and their presence in tailings are reviewed briefly.

Rooted plants obtain oxygen for root growth from both the soil (tailings) and through the plant, depending on the soil availability of oxygen (Luxmore and Stolzy, 1982). Therefore very little oxygen will be transported to the root-zone itself if the oxygen tension of this zone is low i.e., oxygen is supplied to the roots from the above-ground parts. Roots respire and therefore release carbon dioxide into the root zone, along with low-molecular-weight organic matter such as sugars, amino acids and more complex substances. These serve as carbon sources which are essential for microfloral growth i.e., essential in supporting growth of acid-generating bacteria and other micro-organisms. Therefore, increased root penetration is likely to increase nutrient supply to microflora. In addition, roots are physically dynamic structures that increase tailings porosity and permeability by breaking up compacted tailings layers, producing hair fissures which allow increased infiltration of oxygen (and water). The sparse vegetation cover on sections of the tailings with low root -penetration would maintain the chemical characteristics of the fill cover for a longer period of time than would a dense vegetation cover.

4.1.2 Surface around Decant Pond:

The surface characteristics around Decant Pond are schematically presented in Map 6 (Page 29). The outer perimeter is covered by dead cattail stands which had established during higher water levels when the pond was active. Trunks of trees which were cut prior to operation of the pond are now exposed. New populations of cattails have established on the shores of the pond. The perimeter was hydro seeded during reclamation and in some areas patches of grass cover have established along with weedy moss species.

The dominant indigenous species however, are the mosses, *Leptobryum pyriforme* and *Politricum juniperinum* which typically colonize an area after a disturbance. These two species form a significant proportion of the vegetation cover on the exposed surface around Decant Pond.



Map 6. Schematic representation of vegetation surrounding Decant Pond

Both species are acidophilic, as indicated by the lower pH values measured in the substrate around Decant Pond (Table 4, below).

VEGETATION COVER	n	pH X	SD
Tree Stumps	11	5.8	0.9
Dead Cattails	1	7	
Grass	7	5.5	1.3
Moss	13	4.5	0.7
Cattails	7	4.6	0.8
Control Grass	6	5.7	0.4
Control Moss	6	5.1	0.8

Table 4. pH measurements of substrate surrounding Decant Pond

Some pH measurements were obtained outside the boundaries of the pond in undisturbed vegetation covers (Control grass, Control moss). The pH range outside the boundaries of the pond is pH 5.1 to 5.7 and is not drastically different from the pH range measured inside the boundaries of Decant Pond. The colonization pattern by the indigenous species suggests that this exposed area around Decant Pond is not contaminated to a point were recovery, in the form of an indigenous vegetation cover, is not possible.

Two pockets of exposed, oxidizing tailings on the north-western shores of Decant Pond are of concern. The pH in this material is 3.5 to 4.0 and the concentrations of Cu, Fe, Pb and Zn are high (Samples D1 and D2 in Table 5, below). The concentrations in these tailings, which might possibly be mixed with concentrate given their high metal content, are compared to the metal concentrations determined in a sample of dead organic material (sample D3). This type of material is characteristic of sections around Decant Pond, coded TS and DC in Map 6 (tree stumps and dead cattails).

Sample Code	D1	D2	D3
	percent		
Copper	3.88	1.72	0.73
Iron	15.60	14.80	11.90
Lead	0.91	0.42	0.37
Zinc	9.37	5.18	2.90
L.O.I.	26.08	19.46	40.75

Table 5. Analyses of tailings and organic soil analysis collected in the area surrounding Decant Pond

The two tailings samples (D1 and D2) are considerably higher in copper and zinc than sample D3. The oxidizing conditions together with these high concentrations of metals, are undesirable. This material should be covered to prevent further oxidation and release of metals.

The sample D3 has a high organic content (41 %) and represents the material on top of mounds as opposed to the depressions between mounds which are frequently filled with moss carpets. This organic soil material has also adsorbed considerable amounts of zinc (3%).

Loss on ignition at 1000°C provides an estimate of the combined organic matter and sulphur content of a sample. The sulphur contribution was evaluated for all the solid samples and was found for non-tailings samples to range between 0.1 - 2.0%. The tailings, along with the material around Decant Pond (D1, 2 and 3) contain about 10 to 20% sulphur.

Organic matter is considered a good complexing agent for metals which significantly reduces their environmental mobility. The fact that moss carpets develop in the depressions surrounding the hummocks would suggest that the mobility of adsorbed zinc is likely to be minimal. However, some systematic sampling program should be carried out to determine if the conditions described are representative of the areas outlined in Map 6 (Page 29).

4.1.3 Decant Pond and the Mud Lake system characteristics

The water quality in Decant Pond was monitored during 1986 from May to October, in anticipation of a potential acidification of the water since no liming took place this year. The locations of the water sampling stations are given in Map 7 (Page 33).

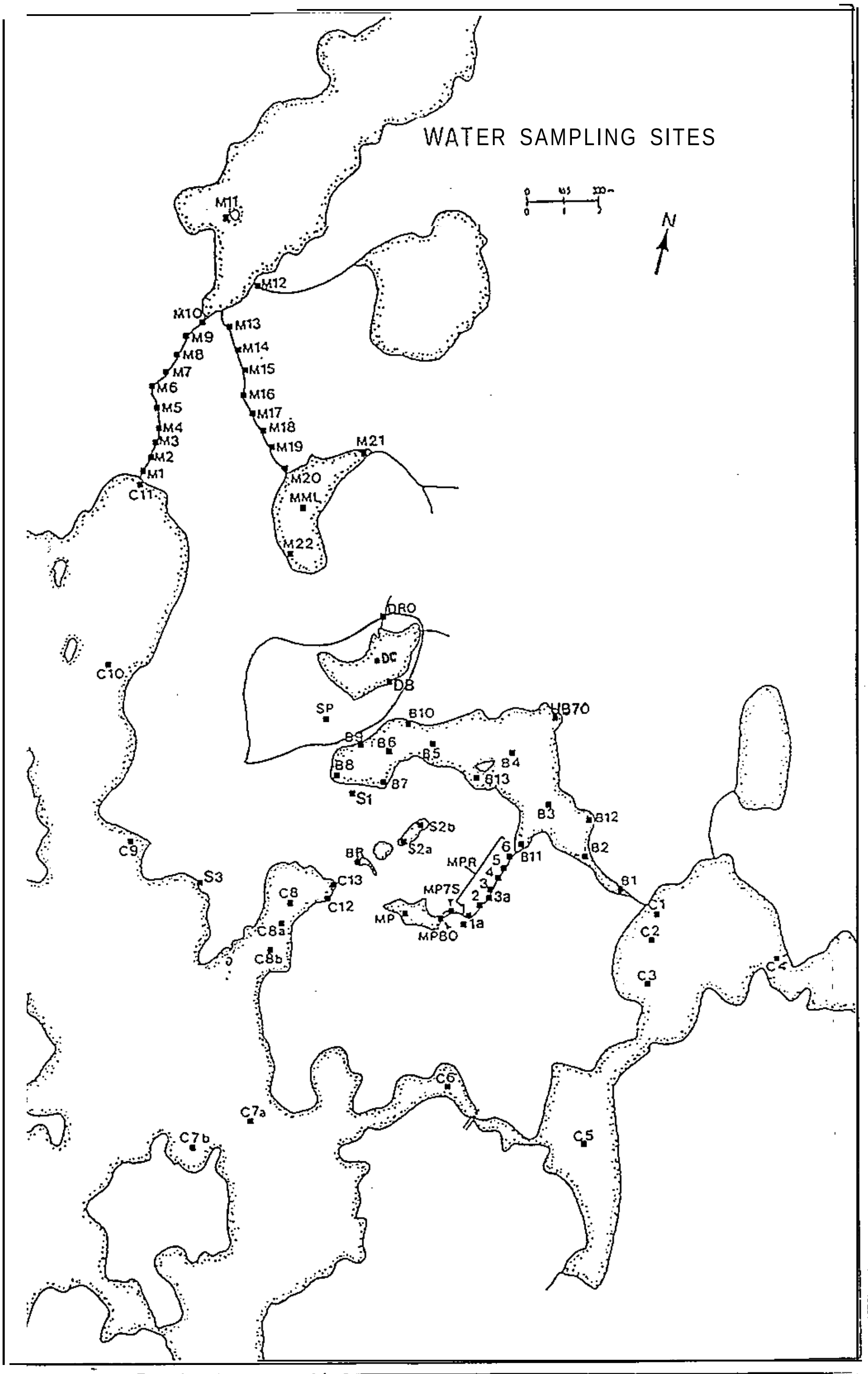
In Table 6 (below), the pH and conductivity values and the concentrations of copper, iron, lead and zinc are reported. A seasonal trend of high concentrations of zinc in the beginning of the year and at the end of the year is evident. The increased zinc concentrations however are not associated with decreased pH of the water as might be expected. In fact the pH increased slightly during the summer months remaining neutral with a mean of 6.7. Electrical conductivity varied little. The trend does not hold for copper, iron and lead, which are present in low concentrations during the summer months.

Table 6
WATER CHARACTERISTICS OF DECANT POND

SAMPLING CODE	DRO 4/05	DRO 6/17	DC 7/24	DRO 8/17	DB ON BEACH	DRO 10/15	DB ON BEACH	MEAN VALUE	STANDARD DEVIATION
pH	6.1	-	7.5	6.5	6.9	6.5	6.5	6.67	0.48
cond:umhos	520	-	800	-	800	700	700	704	114.37
mg\L									
Cu	0.18	0.02	0.02	<0.005	0.01	0.01	0.02	0.04	0.05
Fe	1.63	0.20	0.13	0.02	0.07	<0.1	1.00	0.44	0.63
Pb	<0.01	<0.005	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zn	7.20	1.54	1.10	1.40	1.30	5.70	6.60	3.55	2.60

DRO - Decant run-off; DC - centre Decant Pond; DB - Decant beach
(refer to Map 7, p.33)

Table 6. Water characteristics of Decant Pond



Map 7. Locations of water sampling stations.

Extensive periphytic growth was noted during the summer on all beaches with cattails in Decant Pond. This growth contained high concentrations of zinc (4 to 5 %) and it could be that the reduction in zinc noted during June to August was due to the periphytic growth. The high concentrations in the water of Decant Pond might be a result of spring and autumn run-off. No further data have been collected to support the proposed bioadsorption and the run-off flux. Potential applications of Biological Polishing by the periphytic algal growth in Decant Pond are discussed in detail in section 4.2., with data pertaining specifically to the algae.

Given the concentrations of metals in Decant Pond and the trends noted, it is of interest to determine if the receiving surface water of Mud Lake displays similar seasonal behaviour. The concentrations of the same elements are given in Table 7 (below) for Mud Lake water samples and their dates (Locations indicated in Map 7, Page 33).

Table 7
MUD LAKE WATER CHARACTERISTICS

SAMPLING	MUD	-	-	-	-	-	-	LAKE		
CODE	MML		M21			M22			MEAN	STANDARD
	6\16	7\25		6\16	7\25	4\05	6\16	7\25		DEVIATION
pH	7.56	6.2	6.15	6.1	6.28	6.6	6.1	7.26		
cond	430	475	480	130	150	480	130	435		
mg/L										
Cu	0.02	0.06	0.08	0.02	0.02	0.02	0.02	0.01	0.03	0.02
Fe	0.13	0.36	0.51	0.2	0.32	0.56	0.1	0.58	0.35	0.22
Pb	0.01	<0.01	0.01	<0.005	<0.01	<0.01	0.04	<0.01	<0.01	0.01
|-	0.02	0.03	0.06	0.05	<0.005	0.22	0.04	0.12	0.07	0.066

Table 7: Mud Lake water characteristics.

One station in Mud Lake (M22) was monitored in May, June and July 1986. The highest value of zinc (0.22 mg/l) was reported for May, decreasing similarly to Decant Pond in June, with a slight increase in July. The pH and the electrical conductivity did not change in the three months, ranging from pH 6.1 to 6.7 and conductivity 130 to 480 umhos/cm. Although this seasonal trend is based on only a few samples in Decant Pond and Mud Lake, it is important to determine if this trend persists in the next year and ascertain the underlaying mechanisms.

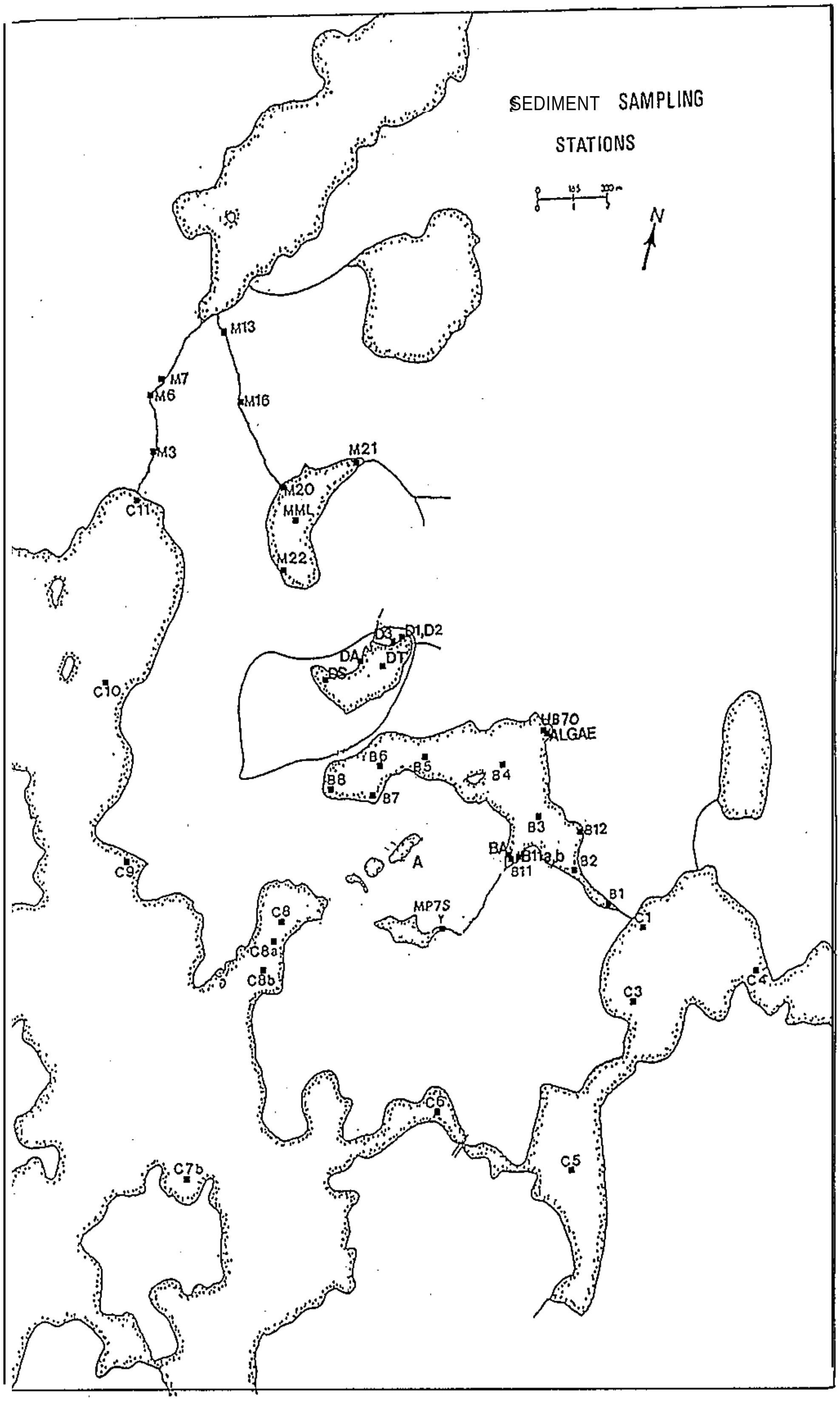
One of the mechanisms affecting metal concentrations in the water could be the interaction of the sediments with the surface water. The sediments in both Decant Pond and Mud Lake were sampled at the locations indicated on Map 8 (Page 36).

The concentrations of Cu, Fe, Pb and Zn are summarized for Decant Pond sediment samples in Table 8 (below).

Table 8
DECANT POND SEDIMENT CHARACTERISTICS

SAMPLING CODE	DECANT SEEP SED.	DECANT BOTTOM LAYER	DECANT SEEP MIDDLE	D.SEEP LOWER TAILS.	DECANT TAILS.	MEAN	STANDARD DEVIATION
Elem.-%							
Cu	0.4	0.6	0.03	0.36	0.43	0.36	0.23
Fe	22	7.9	1.5	7.2	13	10.32	7.25
Pb	0.06	0.17	0.01	0.08	0.25	0.11	0.09
Zn	3.28	3.6	1.45	4.2	2	2.91	1.63
L.O.I.	30.35	7.36	40.97	11.70	12.06	20.49	14.47

Table 8. Metal concentrations in Decant Pond sediment



Map 8. **Sediment Sampling Stations**

Sampling was carried out to determine the metal concentrations in sediments in the centre of the pond and in those that are exposed to acidification due to seepages along the beaches of the dry tailings. It was expected that the acidic seepage which had been discharging on the shores for at least 4 years, would have acidified these sediments. However the samples had a pH of 8.5 to 7.2 with an electrical conductivity of 600 to 800 umhos/cm. The "sediments" are a mixture of fine tailings particles and precipitates from previous liming. The samples show wide variations in zinc concentrations but relatively low concentrations of copper and iron.

The zinc concentrations are, however, relatively high and are therefore of concern in the long term, especially if zinc becomes mobilized from the sediments.

The entire Decant Pond bottom is covered with an extensive cover of lime which has accumulated over time. This layer isolates the underlying fine tailings from the water column. The basic chemical behaviour of zinc is reviewed briefly to clarify the conditions which are required to assure that zinc will not be mobilized from tailings in Decant Pond. Zinc solubility in soils is negatively correlated with calcium saturation and phosphorus compounds present in the soil. Furthermore, zinc mobilization occurs under acidic and oxidizing conditions. It follows that the zinc in the tailings of Decant Pond, underneath the layer of lime representing calcium saturation, is immobile as long as the conditions remain anoxic, reducing and alkaline.

When the wetland is established covering the entire pond, such conditions will be maintained. The organic matter produced by this wetland will result in reducing conditions overlying the lime precipitation below which the fine tailings are located. The organic matter in turn is expected to produce complexing agents which, during run-off, are expected to immobilize metals which might be contributed to the pond by the dry tailings section. Experiments which address the promotion of wetland development are underway and are discussed in section 4.3.

Mud Lake is appropriately named, since shallow water with a depth of about 30 - 90 cm overlies organic sediment which extends 3 - 5 m down to bedrock. Sediment grab samples have been collected in Mud Lake and in the outflow arms leading towards Confederation Lake (Map 8, Page 36). In Table 9, (below), the concentrations of Cu, Fe, Pb and Zn are summarized. All metals concentrations determined in the sediments are low, with a high organic content (L.O.I).

Table 9
SEDIMENT CHARACTERISTICS OF MUD LAKE SYSTEM

SAMPLING CODE	WEST M3 7\25	- M6 7\25	ARM M7 7\25	EAST M13 7\25	- M16 7\25	ARM M20 7\25
Elem.-%						
Cu	0.003	0.004	0.002	0.002	0.01	0.006
Fe	1.9	1.9	1.6	2	1.6	3.9
Pb	0.005	0.005	0.004	0.003	0.01	0.007
Zn	0.01	0.04	0.01	0.01	0.03	0.02
L.O.I.	73.93	78.54	79.97	79.43	79.7	79

SAMPLING CODE	MUD M22 7\25	- 7/25	- MML 7\25	- 7\25	- M21 7\25	LAKE 7\25	MEAN	STANDARD DEVIATION
Cu	0.003	0.003	0.002	0.002	0.004	0.002	0.004	0.002
Fe	1	0.98	1.3	1.4	1.3	1.2	1.67	0.99
Pb	0.004	0.005	0.004	0.005	0.006	0.005	0.005	0.003
Zn	0.02	0.02	0.02	0.02	0.04	0.04	0.02	0.01
L.O.I.	58.82	59.97	54.26	54.43	59.64	58.63	68.03	34.84

Table 9: Metal concentrations in sediments in the Mud Lake system.

If the Mud Lake system had been affected during mine operation or after shut down, concentrations in the sediment might be elevated, particularly those of the metal zinc. However, zinc concentrations are low throughout the entire system, ranging from 0.01 to 0.04 percent. No trends in the concentrations can be detected as the distance from Decant Pond decreases. The sediments in the both arms of the Mud Lake outflow system are rich in organic matter, with values as high as 80 percent, compared to the Mud Lake sediments with about 60 percent organic content. The origin of the additional organic matter is evident if one considers the contribution of detrital l material from the dense vegetation associated with both water coursed (Plate 8, below).

Plate 8. Typical vegetation cover encountered in Mud Lake out-flow

The water in the east arm of Mud Lake and in the outflow can be expected to reflect none of the characteristics of Decant Pond, given the rich organic nature of this watercourse. Water samples were taken in June over the entire length of the outflow channels (Table 10, below).

SAMPLING CODE	EAST 6\16	M14 6\16	"15 6\16	M16 6\16	M17 6\16	M18 6\16	M19 6\16	ARM M20 6\16	MEAN VALUE	STANDARD DEVIATION
pH	6.6	6.7	6.7	6.55	6.3	6.7	6.6	6.5		
cond:umhos	365	380	380	370	370	400	335	360		
mg\L										
Cu	0.03	0.01	0.008	0.01	0.02	0.02	0.02	0.02	0.02	0.01
Fe	0.8	0.32	0.45	2.11	0.63	2.39	0.19	2.41	1.16	0.88
Pb	0.06	0.02	0.04	0.04	0.05	0.03	0.03	0.02	0.04	0.02
Zn	0.2	0.007	<0.005	0.01	<0.005	0.18	0.007	<0.005	0.05	0.06

Table 10: Water characteristics in Mud Lake system.

The pH values ranged from 6.3 to 6.7, with electrical conductivity between 300 to 400 umhos/cm, slightly lower than in Mud Lake, due to additional drainage water. Throughout the Mud Lake system, the concentrations of zinc, copper and lead are in the same range during these months. Iron concentrations however, tend to fluctuate from station to station, particularly in the east arm. Along this part of the outflow creek, several acidic peat bogs (with pH ranging around 3.5) occur and it is likely that the fluctuations of iron noted are related to the drainage from these peat bogs.

In summary, the data collected on the Mud Lake system do not provide any evidence that detrimental effects on the water quality and the sediments have occurred due to the discharges from Decant Pond.

4.1.4 The Mill site

High metal concentrations in any mining complex are normally associated with the mill site, where concentrates are handled. This is also the case at South Bay, as is exemplified by the characteristics of Mill Pond (Table 11, below).

SAMPLING CODE	MP1	MILL POND	MILL POND A	B	C	MP aft fertl.	MILL POND	MILL POND	MEAN	STANDARD DEVIATION
	5\05	6\16	7\25	7\25	7\25	7\25	8\17	10\18		
mg\L										
Cu	109	10.9	3.6	3.1	24	3.4	0.68	16	21.34	36.30
Fe	9.3	<0.005	0.09	0.16	0.38	0.06	0.05	14	3.00	5.48
Pb	0.82	0.02	0.01	0.02	0.11	<0.01	<0.01	<0.01	0.12	0.28
Zn	390	206	212	194	259	221	118	173	221.63	79.23

Mill Pond A. B, C refer to three locations around the pond.
(refer to map of sampling sites)

Table 11: Metal concentrations in water of Mill Pond

This pond is, on the average, about 0.5 m deep, with one "hole" about 1.5 m deep. The pond receives some run-off at the south side and some seepage from the waste rock pile. Both these water sources for the pond are small. During snowmelt and rainfall, additional water is added to Mill Pond, including that which accumulates in the abandoned mine and mill buildings. A dam was built at the overflow of Mill Pond towards the east. Here effluents were neutralized and then discharged towards a small swampy ravine.

In essence, Mill Pond has served in the past as a general catchment lagoon for mine sump slimes and the run-off from the mill site. The pond was, therefore, expected to display varied concentrations of metals, which indeed is the case, with concentrations of copper ranging from 109 mg/l to 0.68, and zinc concentrations from 390 to 118 mg/l.

The metal concentrations were highest for all 4 metals in May and their behaviour was quite erratic throughout the following four months. In water samples collected since shutdown by BP-Selco, the concentrations of total (unfiltered) zinc ranged from 14.4 to 620 mg/l, and for total copper from 2.47 to 143.0 mg/l, reflecting similarly large variations as were observed during 1986. The erratic variations in metals concentrations are typical for Mill Pond, and any deviation from this type of behaviour can only be expected after clean-up of the site is completed.

The overall variation in the pH values was generally quite large, ranging from 2.9 to 6.8, while electrical conductivity ranged from of 600 to 2000 umhos/cm. It is suggested that given the water sources for Mill Pond described earlier, the present fluctuations in metal concentrations do not reflect the conditions that will prevail after shutdown of the site.

The overflow from Mill Pond runs towards Boomerang Lake through Mill Pond run-off, a small ravine. The ravine is covered with extensive deadfall and moss carpets consisting mainly of <u>Pohlia </u>nutans, a semi-aquatic, metal-tolerant, weedy moss. In Table 12, (below), the concentrations of copper, iron, lead and zinc are given for stations MP1 to MP6, and for D-Dam, a station established immediately below Mill Pond. The station MP6 is located about 3 meters away from Boomerang Lake (Map 7, Page 33).

Table 1 2
WATER CHARACTERISTICS OF MILL POND RUN-OFF

SAMPLING CODE	MP1 5/24	6/17	D-DAM 8/17	10/15	MP2 5/24	6/17	7/21	8/17	MP3 5/24	6\17	7/21	8/17	10/15
pH	3.66	3.8	5.2	4.2	3.6	3.81	5.2	-	4.17	4.95	5.6	-	5.6
cond:umhos	294	230	370	110	320	268	155	-	220	120	190	-	50
mg\L													
Cu				0.75			3.1			1.09			
Fe	0.58	0.58 2.2	0.95 2.3	4.9	0.53	0.46	1.3	2.2 1.1	0.37 1.9	0.27	0.42 0.4	0.8 0.4	0.59 0.91
Pb	0.04	0.04	<0.01	<0.01	0.01	0.03	0.02	<0.01	0.01	0.01	<0.01	<0.01	<0.01
Zn	15	19.9	12	4.5	25	28.3	24	12	16	10.8	3.1	6.2	2.5

SAMPLING CODE	MP3a 8/17	10/15	MP4 5/24	6/17	7/21	MP5 5/24	6/17	7/21	MP6 5/24	6/17	7/21	MEAN VALUE	STANDARD DEVIATION
pH		4	3.73	4.18	-	3.86			3.98	4.1	-		
cond:umhos	-	80	255	190	-	305	4.21	-	270	205	-		
Cu mg\L		1		2.25			190						
Fe	0.9:	2.7	0.3 2.7	0.35	0.69 1.7	2.6	2.02	1.4	2.2	2.1	1.5	1.84	1.1
						0.69	0.39	0.67	0.5	0.38	0.51	0.93	0.86
Pb	0.01	<0.01	<0.005	0.05	0 . 0	1 <0.005	0.02	0.03	0.03	0.02	0.02	0.02	0.01
Zn	12	4.3	23	20.8	13	23	20.6	13	25	23.7	15	15.53	9.49

Table 12. Water ccharacteristics of Mill Pond run-off

The metal concentrations in the water samples collected over the season display two interesting characteristics. One observation relates to the differences between sampling stations MP3 and MP3a, and the second to the seasonal decreases noted in the metal concentrations for all stations in the ravine.

Sampling station MP3 is generally associated with somewhat higher pH values (4.1 to 5.6) and lower concentrations of copper and zinc than all the other stations in the ravine. This would indicate a 'cleaner' water supply originating from the east side of the ravine. Sampling station MP3a was established later in the year, representing water draining across from MP3 from the west side of the ravine, i.e. from the mill site. A comparison of the water collected on the same day from both stations shows that MP3 is lower in concentrations of zinc and copper. These differences persist between the two sampling locations when sampled at a later date, but they are less pronounced (Table 12, Page 43).

Temporal changes in the water quality in this ravine are also indicated. The concentrations of zinc and copper decrease significantly from May to October in all sampling stations. These reductions might indicate that the ravine receives an initial loading of contaminated water from the mill site during spring run-off, which is gradually diluted toward the end of the season.

It would follow that if the ravine gets its main load of contaminated water from the mill site then, as the metal loading from the mill site is reduced, the contamination in the ravine will also be reduced in time. A reduction in metal release could however, take a considerable length of time. The noted differences in water quality between sampling points MP3 and MP3a from the east and west side of the ravine, could indicate that a larger area than the mill site is contaminated due to wind transport of concentrate. The zinc concentrations in water from samples collected at MP3 (the east side of the ravine) are relatively high, although lower than for the other stations . The concentrations of copper on the other hand are particularly low, with 0.53 mg/l compared to concentrations generally of > 1 mg/l. This difference could be a reflection of differences in moisture content of either copper or zinc concentrate, differences in the drying operations and differences in production rates.

These suggestions are based only on one set of sampling stations and their differences in copper and zinc concentrations. To obtain a clearer understanding of the zinc loadings to Boomerang Lake in the long term, the distribution of metals in the immediate vicinity of the Mill site should be investigated.

4.1.5 Boomerang Lake

Boomerang Lake is a generally shallow lake with its deepest location of about 5 m, slightly to the west of the oentre of the lake, close to a small island. Given the shallow nature of this lake, it is well mixed and turns over rapidly in spring. The water quality in the entire lake is therefore quite consistent and does not change with the seasons as indicated by the concentrations of copper, iron, lead and zinc summarized in Table 13 (below).

Table 13
WATER CHARACTERISTICS OF BOOMERANG LAKE

SAMPLING CODE	B7 6\16	7\25	B8 6\16	7\25	B9a 5\05	B6 7\25	B5 7\25	8\17	10\15	B4 6\16	7\25
pH	4.3	4.1	4.3	4.1	4.2	4.15	4.2	-	4.2	4.3	4.25
cond:umhos	360	390	380	400	240	395	390	-	250	340	390
mg\L											
Cu	0.18	0.22	0.19	0.19	0.18	0.18	0.19	0.20	0.10	0.18	0.19
Fe	1.91	1.50	1.95	1.50	1.67	1.50	1.20	0.82	1.00	1.38	1.00
Pb	0.01	0.03	<0.005	0.01	<0.01	0.04	0.01	0.03	<0.01	0.01	0.02
Zn	8.96	9.40	8.95	9.20	7.40	8.80	9.10	8.50	7.40	8.84	9.00

SAMPLING CODE	B13 4\05	B3 6\16	7\25	8\17	10\15	B11 4\05	6\16	* 7\25	8\17	10\15	B12 6\16
pH	4.6	4.3	4.3	5.4	4.5	4.2	4.25	4.3	-	4.4	-
cond:umhos	240	355	390	330	240	250	340	380	-	240	-
mg\L											
Cu	0.19	0.20	0.13	0.14	0.09	0.21	0.20	<0.005	0.15	0.10	0.18
Fe	1.67	1.37	0.80	0.74	0.80	1.68	1.29	1.60	0.69	0.70	1.34
Pb	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.005	<0.01	0.01	<0.01	0.01
Zn	7.40	8.86	7.30	8.50	7.40	7.60	8.99	8.30	8.50	7.30	8.76

SAMPLING CODE	B2 6\16	7\25	B1 4\05	6\16	7\25	8\17	10\15	MEAN VALUE	STANDARD DEVIATION
pH	4.2	4.4	4.2	4.23	4.7	-	4.4	4.34	0.26
cond:umhos	360	380	220	360	275	-	230	325	65.91
mg\L									
Cu	0.18	0.19	0.18	0.18	0.18	0.14	0.10	0.16	0.05
Fe	1.22	1.10	1.54	0.79	0.54	0.68	0.50	1.19	0.42
Pb	0.009	0.03	0.01	0.005	0.04	<0.01	<0.01	0.01	0.01
Zn	9.09	9.00	7.20	9.13	9.10	8.50	6.90	8.39	0.77

Table 13: Water characteristics of Boomerang Lake

The sample stations are arranged in Table 13 (Page 46), in order of decreasing distance from the tailings dam (B6 to B1) towards the outflow of the lake. Sampling stations B7 and B8 are just offshore from small tailings spills. The locations are shown in Map 7 (Page 33).

The measured values of pH and electrical conductivity are very consistent throughout the year, with a mean pH value of 4.3 $\pm$ 0.26 and a conductivity of 325 $\pm$ 66 umhos/cm. These values and the determinations of dissolved oxygen concentrations for the deeper locations in the lake, reflect the fact that the lake is entirely mixed. A chemocline which might have been present in close proximity to the tailings dam was not evident.

Boomerang Lake can be meaningfully described as having low mean dissolved (filtered 0.45 um) concentrations for three of the four metals, with small standard deviations. For copper, the concentration representative for 1986 is 0.16 $\pm$ 0.05 mg/l, for iron 1.2 $\pm$ 0.4 mg/l, for lead 0.01 $\pm$ 0.01 and finally for zinc 8.3 $\pm$ 0.8 mg/l. These values clearly indicate that only the zinc concentrations are elevated in this water body.

Some obvious point sources of contaminant inflows into the lake have been considered. These are Mill Pond run-off, the tailings spill beaches and seepages from the tailings. These locations could represent continued contamination sources if metal plumes are present due to significant water flow. However in the samples collected directly at these locations (B11, B8 and B7, Map 7) higher metal levels are not evident on the shore. This suggests that the flows from these locations are minimal during the summer months and it may indicate that the metal loading to the lake occurs mainly on a seasonal basis, during spring. If this is indeed the case, any remedial measures to be undertaken to reduce the zinc input to the lake must take into consideration this behaviour. Such measures are discussed in the following sections of the report.

Metal inputs into the lake should be reflected in the metal concentrations in the sediment at or near the input points. Due to their interactions with the water column, sediments often act as scavengers of metals. The sediments in Boomerang Lake, at the sampled locations indicated in Map 8 (Page 36), are summarized in Table 14 (below).

Table 14
SEDIMENT CHARACTERISTICS OF BOOMERANG LAKE

SAMPLING CODE	B7 6\16	B8 6\16	B6 6\16	B5 5\22	B4 5\22	UB70 6\16	B3 5\22
pH	6.85	671	6.2			6.3	
cond. umhos	110	300	440	-	-	140	
%							
Cu	0.13	0.08	0.01	0.03	0.04	0.003	0.01
Fe	23.00	18.00	2.80	3.90	4.00	1.90	3.00
Pb	0.13	0.17	0.01	<0.001	<0.001	0.009	<0.001
Zn	0.89	0.40	0.49	0.90	1.00	0.09	0.40
LOI	16.64	14.75	39.49	39.11	41.22	1.76	41.18

SAMPLING CODE	B11 5\22	B11a 5\22	B11b 5\22	B12 6\16	B2 5\22	B1 5\22	MEAN VALUE	STANDARD DEVIATION
pH	-	-	-	6.1	-	-		
cond. umhos	-	-	-	160	-	-		
%								
Cu	0.03	0.01	<0.001	0.002	0.01	0.02	0.03	0.03
Fe	1.90	1.60	1.40	1.40	2.80	2.00	5.21	5.45
Pb	<0.001	<0.001	<0.001	0.008	<0.001	<0.001	<0.03	0.04
Zn	1.20	0.50	0.08	0.006	0.10	0.70	0.52	0.38
LOI	22.99	6.39	2.7	0.78	34.52	21.19	21.75	15.5

Table 14: Sediment characteristics for Boomerang Lake

The samples B7 and B8, collected offshore from the tailings spills, represent metal concentrations in tailings. Those "sediments" have the highest concentrations of all four metals and are particularly high in iron. Their pH values ranged from 6.5 to 6.8, and their electrical conductivity from 110 to 300 umhos/cm. For the remaining sediments in Boomerang Lake, the zinc concentrations range between 0.5 and 1 %. The concentrations of copper and lead are essentially in the same low concentration range for all sediment samples. The organic matter content in the sediments ranges from 0.78 % to 42%.

The samples B11, Blla and Bllb have been taken at 10 m intervals leading away from the shore at Mill Pond run-off. The concentrations of zinc drop from 1 % by half to 0.5 % in station Blla, and are further reduced to about one-sixth (0.08%) at station Bllb. This decrease might be interpreted as indicative of an input of zinc from Mill Pond run-off, however the concentrations of zinc also appear to be related to the organic matter content of the sediments. The samples Blla and Bllb have low L.O.I values, considerably lower than sample B11. In fact in reviewing all zinc concentrations in sediments in relation to the organic matter contents, it is noted that the lowest zinc value (0.006 %) was determined in the sample with the lowest L.O.I value (0.78 %). The sediment data for Boomerang Lake therefore suggest that organic matter appears to provide a sink for zinc, despite the acidic nature of the lake. Thus the interaction of organic matter and zinc in the sediments of the lake does not facilitate a determination of point sources for the zinc contamination in the lake.

Measures to curtail the zinc concentrations in the water of Boomerang Lake in the long term should be based on the chemical behaviour of zinc in this system. Some aspects of zinc chemistry in sediments were previously discussed in relation to the tailings in Decant Pond. In Boomerang Lake, the behaviour of zinc which is in the water column is of relevance. Changes in particulate and dissolved metal concentrations in the water are believed to be directly or indirectly related to the carbon cycle in the lakes. Salomons and Forstner (1984) concluded, based on a five-year study of a lake in which mechanisms that affect dissolved and particulate matter were investigated, that adsorption processes are the main factor in the removal of zinc, cadmium and chromium from the water column. Copper, in contrast to the metals previously mentioned, is hardly removed by adsorption.

This chemical behaviour of zinc appears to be reflected in the Boomerang Lake system. The relationship between the zinc concentrations and the organic matter content of the sediments indicates that the expected adsorption processes for zinc are active in the water column. Adsorption will occur for example on phytoplankton, representing a form of particulate matter which will transfer zinc to the sediments. It follows that recovery of Boomerang Lake can be expected in the long term as a result of decreasing contaminant inputs and increasing organic matter production in the lake. The composition and the behaviour of phytoplankton and periphyton in Boomerang Lake has been investigated. The results are presented in a later section in connection with the environmental impacts and remedial measures suggested.

4.1.6 Confederation Lake

To establish which conditions of the environment require protection from potential long-term effects of the abandoned mine site, the characteristics of Confederation Lake were determined. Those characteristics also serve to establish the parameters that are of environmental concern with respect to the effects from the waste management area at South Bay.

Water quality along the shores of the waste management area was monitored with repeated sampling at station Cl, the outflow of Boomerang Lake, at station C8, a bay which might receive run-off from the mine site, and at station C11, the outflow from the Mud Lake system (Map 7, Page 33). Other locations in Confederation Lake have been sampled once during the summer season as reference points. In Table 15 (Page 52), the concentrations of copper, iron lead and zinc in the samples are summarized.

Table 15
THE WATER CHARACTERISTICS OF CONFEDERATION LAKE

SAMPLING CODE	C1				C2	C3	C4	C5	C6	C7	C8			
	6\17	7\26	8\17	10\15	6\17	6\17	6\17	6\17	6\18	6\18	6\18	7\26	8\17	10\15
pH	7.3	7.15	6.8	6.3	7.5	8	7.5	7.5	7.3	7.5	7.2	7.3	7.2	6.9
cond:umhos	60	38	270	80	48	40	40	43	43	50	52	50	60	50
Elem.mg/L														
Cu	<0.005	0.005	<0.005	0.21	0.02	<0.005	<0.005	<0.005	0.02	<0.005	<0.005	0.005	<0.005	0.01
Pb	0.01	0.06	0.05	0.9	<0.005	<0.005	<0.005	<0.005	0.26	0.08	0.01	0.06	0.02	<0.1
Zn	0.01	<0.01	<0.01	<0.01	0.02	<0.005	<0.005	<0.005	<0.005	0.01	<0.005	<0.01	<0.01	0.41
	0.18	0.03	0.75	1.7	0.1	0.03	0.02	0.04	0.14	0.23	0.06	0.03	8.6	0.13

SAMPLING CODE	C9	C10	C11				C12		C13		MEAN	STD. DEV.
	6\18	6\18	6\18	7\26	8\17	10\15	6\18	7\26	6\18	7\26		
pH	7.3	7	7	7.2	7.7	6.6	-	7.2	7.1	7		
cond:umhos	54	68	70	50.5	60	50	-	50	58	50		
Elem.mg/L												
Cu	<0.005	<0.005	0.01	0.006	<0.005	0.005	0.009	0.02	0.04	0.02	<0.02	0.03
Fe	0.005	<0.005	0.07	0.09	0.02	0.89	0.03	0.24	0.02	1.6	0.2	0.3
Pb	0.01	0.006	<0.005	0.02	<0.01	<0.01	<0.005	0.02	0.03	0.06	<0.03	0.06
Zn	0.05	0.03	0.04	0.03	0.02	0.33	0.18	0.09	0.11	0.1	0.54	1.26

Table 15. The water characteristics of Confederation Lake

As expected, the concentrations of all metals are low, with the exception of the zinc concentrations in two samples at stations Cl and C8. The zinc concentration in the October sample from Cl represents the highest concentration found during the season. This could be a reflection of increased flow rate from Boomerang Lake which occurred as a result of precipitation during autumn.

It is suspected that the C8 August value for zinc is erroneous, since the concentrations before and after this sampling date fall within much lower concentration ranges. It is possible that the sample was contaminated during filtration. The likelihood of an erroneous result is further supported by the concentrations determined in sampling locations Cl2 and C13, directly at the shores of the mill site. Slight stains on the beach in these locations indicated possible sources of acidic seepage, but the zinc concentrations here are considerably lower than the value obtained for station C8 in mid August.

Metal concentrations in water bodies associated with mineralized areas can generally be expected to be somewhat elevated, however this is not indicated for the water in Confederation Lake. Some reflection of the mineralization should, however, be evident in metal concentrations in the sediment. The sediment samples were collected at all water sampling stations in Confederation Lake. The concentrations of copper, iron, lead and zinc are presented in Table 16 (below).

Table 16
SEDIMENT CHARACTERISTICS OF CONFEDERATION LAKE
(7\25\86)

SAMPLING CODE	C1	c3	C4	C5	C6	C7b	C8a	C8b	C9	C10	C11	MEAN	STANDARD DEVIATION
pH	6.25	6.2	6.3	6.35	6.5	6.7	6.2	6.6	6.4	-	6.2		
cond:umhos	70	80	95	80	90	72	180	160	70	-	70		
Elem.-%													
Cu	0.05	0.005	0.001	0.005	0.009	0.001	0.01	0.009	<0.001	0.002	<0.001	0.008	0.011
-	1.1	2.7	1.4	1.5	1.7	1.6	1.7	2.7	1.2	2.7	1.2	1.63	0.99
Pb	0.006	0.007	0.008	0.007	0.008	0.007	0.01	0.01	0.009	0.009	0.009	0.008	0.004
Zn	0.9	0.01	0.01	0.01	0.07	0.01	0.17	0.16	0.01	0.008	0.006	0.11	0.19
L.O.I.	63.1	112.39	12.39	54.6	119.48	6.33	118.66	160.58	2.2	1.18	2.84	23.07	24.22

Table 16: Sediment characteristics for Confederation Lake.

The concentrations in the sediments are consistently low, with mean values of 0.008 % for copper, 1.6% for iron, and 0.008% for lead. In two locations, in the outflow from Boomerang Lake (Cl), and in the bay of the mill site (C8a and C8b), the sediments have higher zinc concentrations compared to the remaining stations in Confederation Lake. Those locations also have high organic matter contents in the sediments, suggesting a pattern similar to that found for Boomerang Lake. Comparing the metal concentrations in the sediments of Boomerang Lake and Confederation Lake, it is apparent that the concentrations are very similar, if the tailings "sediments" are excluded from the mean calculations. Copper in Boomerang at 0.01 % compared to 0.008 % in Confederation sediment, iron 2.4. % compared to 1.6 % , lead 0.003 % compared to 0.008 % and finally zinc in Boomerang sediment with 0.46 % compared to 0.11 % in Confederation Lake.

4.2.1 Water quality comparisons and environmental considerations

In the previous section, all major parts of the waste management area have been described and their behaviour has been discussed. Relative differences and interactions between the various parts of the South Bay mine site were not discussed. These aspects must be taken into account in planning for the prevention of environmental degradation of the waste management area, as they are likely indicative of the types of changes that can be expected in the absence of remedial measures. The differences between the various components of the waste management area also indicate, to some degree, the magnitude of the changes to be expected in the long term, i.e. they provide a measure of the worst-case scenario, a term commonly associated with environmental impact assessment.

A comparison of the sediment concentrations of the four metals discussed previously indicates, for example, the relative differences in concentrations ranges between tailings, here considered as one of the main sources of contamination, and the natural unaffected portions of the area. In Table 17 (below), the lowest and the highest values reported for Boomerang Lake, Confederation Lake, Mud Lake and its east arm, and Decant Pond are summarized.

SITE DESCRIPTION	Boomerang Min-Max	Conf. Lake Min-Max	Mud Lake Min-Max	Mud East Min-Max	Mud West Min-Max	Decant sea. Min-Max
SAMPLING CODE	----- 19-22	C1-C11	M21,22;MM1	M13,16,20	M3,7	-
elements-%						
Cu	<0.001-0.13	<0.001-0.05	0.002-0.004	0.002-0.01	0.002-0.003	0.03-0.43
Fe	1.4-23.0	1.1-2.7	0.98-1.4	1.6-3.9	1.6-1.9	1.5-22.0
Pb	<0.001-0.17	0.006-0.01	0.004-0.006	0.003-0.01	0.004-0.005	0.01-0.25
Zn	0.005-1.2	0.006-0.9	0.02-0.04	0.01-0.03	0.01	1.45-4.2
L.O.I.	0.78-41.22	1.18-63.10	54.26-59.97	79.00-79.70	173.93-79.43	7.36-40.97

Table 17. A comparison of the sediment concentration ranges for the South Bay Mine site and its vicinity.

The concentration ranges for Confederation Lake and Mud Lake are the same for all four metals. The minimum values for the Boomerang Lake sediments are also in the same range as those for the sediments in the other two water bodies, whereas the maximum values for Boomerang Lake approach the ranges reported for Decant Pond sediments, or tailings. The largest concentration ranges are clearly associated with Decant Pond. This comparison indicates that with respect to remedial measures, emphasis should be placed on determining the sediment/surface water interactions in Decant Pond. The sediment in Boomerang Lake are not contaminated to a degree which presents concern in the long term, 'given that the concentration ranges overlap with those encountered in the natural uncontaminated environments of Mud Lake and Confederation Lake.

A similar comparison between the various components of the waste management area can be carried out using the concentrations of copper, iron lead and zinc in the water samples listed in Table 18 (Page 57).

Cu, Fe, Pb AND Zn CONCENTRATIONS IN WASTE MANAGEMENT AREA
MAY-OCTOBER, 1986

AREAS	Cu	Fe	Pb	Zn	pH	cond
	RANGES (mg/L)					
In Mill Pond	0.68-109	<0.005-14	<0.01-0.82	118-390	2.9-5.7	200-1900
Mill Pond-Outflow channel	0.40-3.5	0.27-2.7	<0.005-0.05	2.5-28.3	3.6-5.8	80-268
In Boomerang	<0.005-0.22	0.5-2.4	<0.005-0.04	6.9-9.4	4.2-4.85	220-420
In Lost Bay (C1-C4)	<0.005 0.21	<0.005-0.9	<0.005-0.02	0.02-1.7	5.8-8.0	40-250
Tailings seepages	<0.005-0.10	300-413	0.14-0.32	51.8-199	2.8-5.4	2100-3400
Leaving Decant	<0.005-0.18	0.02-1.63	<0.005-0.01	1.1-7.2	6.1-7.8	520-2700
Mud Lake	0.006-0.08	0.1-0.58	<0.005-0.04	<0.005-0.22	5.0-7.56	130-480
Mud Lake Outflow (E)	0.008-0.03	0.19-2.41	<0.01-0.06	<0.005-0.28	6.1-6.7	300-400
Confederation (C7-C11)	<0.005-0.01	<0.005-0.09	<0.005-0.02	0.02-8.6	5.84-7.5	40-120
Control 6/18/86	0.07	1.12	<0.005	0.08		
Control 6/16/86	0.02	0.02	0.007	0.02		
Control 7/26/86	0.05	0.82	<0.01	1.10		

Table 18: Water quality parameters for South Bay Mine site and its vicinity.

Results of water analyses are often discussed without any consideration of a potential variability in the metal concentrations as a result of the sampling procedure. The concentrations of copper, iron, lead and zinc are given for control water in Table 18 (Page 57). The water used for rinsing of the filtration apparatus (tap water of the tailor from Confederation Lake, and distilled water) was filtered through 0.45 urn and acidified at the end of the sampling period. This same procedure was carried out between samples which were filtered in sequence of the "expected cleanest to the dirtiest". Such procedures are particularly important for water samples associated with chemically reactive waste materials.

Metal concentrations of natural systems, particularly those associated with waste materials, should not be interpreted in the absence of reference or control samples. These concentrations serve therefore, as reference values for an interpretation of the concentration ranges found in the water at the various locations of the South Bay waste management area and the receiving environment. Differences between minimum and maximum values which are in the same range as the concentrations reported in the "control samples" are insignificant, since they may not necessarily reflect the range for the water body described, but rather represent an artifact from the sampling procedure.

For copper the control values range from 0.02 to 0.07 mg/l which indicates that for all areas evaluated, only Mill Pond and

Mill Pond Outflow are above the concentration range which is typical for the area. The copper concentrations in the tailings seepages are surprisingly low. Copper therefore appears to be mainly associated with the Mine site and not with the tailings.

Iron concentrations in the control samples range from 0.02 to 1.1 mg/l. The concentration ranges for Lost Bay, Confederation Lake and the Mud Lake system represent "background" values. In the East arm of the Mud Lake outflow the highest value reported for iron was 2.4 mg/l, similar to maxima in Boomerang Lake, in Decant Pond and in Mill Pond outflow. The strongest source of iron at the site is the tailings seepages where iron concentration ranges from 300 to 413 mg/l. In Mill Pond, Fe concentration ranges vary widely, from the detection limit of <0.005 to 14 mg/l, which reflects, as previously discussed wide variations in this waterbody due to the varying contributions from different sources.

The lead concentrations display the same pattern as the iron concentrations, with a very wide range in Mill Pond (<0.01 -0.82 mg/l) and with consistently high values in the tailings seepages (0.14 to 0.32 mg/l). All other water bodies evaluated show background concentrations, with minimum values of 0.005, and maxima only slightly over the maximum value of 0.01 mg/l for the control samples.

It is evident from a comparison of the zinc concentration ranges, that remedial measures to reduce zinc releases are requires for Mill Pond, Mill Pond run-off (outflow), Boomerang Lake and the tailings seepages. The concentration ranges for Lost Bay, Confederation Lake and the Mud Lake system are within background concentrations for the area. Freshwater concentrations reported for zinc in the literature range from 0.005 to 0.05 mg/l (Allen et al., 1974). Given the zinc sulfide mineralization in the area, the mean concentration of zinc 0.19 $\pm$ 0.36 mg/l (excluding the erroneous value for station C8) for Confederation Lake is only slightly higher than freshwater reported generally. Monitoring data have been collected by BP-Seloo for Confederation Lake since 1972. The mean annual zinc concentrations based on 6 to 20 samples per year range from 0.8 to 0.01 mg/l (total, unfiltered). Nearly each year has one or two records with extremely high zinc concentrations resulting in unrealistic high mean values as for example in 1978 3.5 mg/l and in 1984 an average 16.4 mg/l. Those mean annual values have been ignored and are not considered in the annual range given, which is considered representative of Confederation Lake.

Basically the waters of Confederation Lake and the Mud Lake system do not show any effects from the presence of the South Bay mining operation and the associated waste material. The pH of the water is neutral to alkaline with electrical conductivities ranging from 40 to 400 umhos/cm, the higher values being those associated with the Mud Lake outflow channels.

Within the waste management area acidic conditions are encountered in Mill Pond with a wide range of pH values from 2.9 to 5.7.

This suggests that local acid-generating sources exist. The same is indicated by the pH values for the Mill Pond run-off area, ranging from 3.6 to 5.3. The electrical conductivity in Mill Pond also exhibits a wider range with higher values than that in the Mill Pond run-off. The waters with the highest conductivities on the site are those of Decant Pond and the tailings seepages. The relatively high conductivity values (130-480) in the Mud Lake system, in combination with higher pH values (5.0 - 7.6) suggest that the conductivity source here is different from those related to acid generation.

The pH, metal concentration and electrical conductivity ranges in Table 18 (Page 57), indicate the natural variations of these parameters in each location sampled during this investigation. The waters with the highest ranges of all parameters are those of Mill Pond, the tailings seepages and Decant Pond. Those Locations are the major areas of concern and they must receive priority when remedial measures for close-out of the site are being considered. Based on the comprehensive overview of the interactions between the various components of the site, secondary importance may be assigned to Boomerang Lake.

From an environmental point of view the elements discussed previously are those which are dealt with in the regulatory process. Concentrations of other metals for which water quality criteria have been developed were also determined during this investigation, to identify any other potential metal problems.

The concentrations ranges for As, Cd, Cr , Hg, Mo , Ni and Se are presented in Table 19 (Page 63). The sequence of arrangement of water bodies is the same as in Table 18 (Page 57), reflecting the most obvious surface water flow direction from the waste sites to the receiving environment. When one compares these metal ranges in the waste site and in the receiving environment, two points emerge. For all elements, considering the surface flow from Mill Pond through Boomerang Lake to Lost Bay, and from Decant Pond through the Mud Lake system to Confederation Lake, the metal concentrations range from values below the detection limit to values in the same order of magnitude as those in the control samples. For most metals, the maximum values are within the concentration ranges reported for the "control values" in these waters. One exception to this might be arsenic for which the mean concentration (calculated assuming the upper value of 0.005 mg/l when present at the detection limit) for Confederation Lake water is 0.07 $\pm$ 0.05 mg/l for 1986, a value identical to the mean for Boomerang Lake of 0.08 $\pm$ 0.07 mg/l. It is likely that these concentrations are due to the presence of arsenopyrite in the mineralization of the area.

Considering the concentration ranges of these metals in the tailings seepages, it is evident that none of the concentration ranges give rise to concern, since even the highest values reported are low. The same holds true for Mill Pond. Thus, as was already concluded based on an analysis of the metals previously discussed,

WATER QUALITY PARAMETERS FOR WASTE MANAGEMENT AREA
MAY-OCTOBER, 1986

AREAS	RANGES ((mg/LL))						
	As	Cd	Cr	Hg	Mo	Ni	Se
In Mill Pond	<0.01-0.4	<0.005-2.0	<0.005-0.01	<0.01-0.2	0.18-0.61	0.01-0.08	<0.005-0.18
Mill Pond-Outflow channel	<0.005-0.18	0.007-0.11	<0.005-<0.001	<0.005-0.07	<0.01-0.06	<0.005-0.06	<0.005-0.07
((I" Boomerang II	<0.005-0.36	<0.005-0.02	<0.005-0.01	<0.005-0.07	<0.005-0.06	<0.005-0.02	<0.01-0.07
In Lost Bay (C1-C4)	<0.005-0.15	<0.005-0.04	<0.005	<0.01	<0.005-0.01	<0.005-0.03	<0.005-0.07
In Tailings Seepages	0.62-1.2	0.009-0.03	0.03-0.06	<0.01-0.27	0.1-0.34	<0.01-0.16	0.43-0.93
Decant	<0.01-0.69	<0.005-0.02	<0.005-<0.01	<0.01-0.12	<0.01-0.05	<0.005-<0.01	<0.005-0.07
Mud Lake	0.02-0.15	<0.005-0.51	<0.005-<0.01	<0.01-0.08	<0.01-0.02	<0.01-0.02	<0.005-0.04
(Mud Lake Outflow (E)	<0.005-0.14	0.009-0.39	<0.005-0.01	<0.01-0.04	<0.005-<0.01	0.007-0.03	<0.005-0.07
Confederation (C7-C11)	<0.005-0.13	<0.005-0.04	<0.005	<0.01-0.02	<0.005-0.01	<0.005-0.01	<0.005-0.05
Control 6/18/86	<0.005	<0.005	<0.005	0.03	0.01	<0.005	0.02
Control 6/16/86	0.06	<0.005	<0.005	0.09	0.01	<0.005	<0.005
Control 7/26/86	<0.005	<0.005	<0.005	<0.01	0.01	<0.01	<0.01

Table 19: Concentrations of other metals in waters of the South Bay Mine site and vicinity

close-out measures which concentrate on the retention of contaminants from these two sources, will address adequately the prevention of environmental degradation considering all potential sources of metal contamination to the surface water.

Finally, water quality can be assessed on the basis of the concentrations of macroelements and nutrients. Environmental degradation is associated with increased concentrations or shifts in the ratios of these elements, as, for example, in the well-known relationship between phosphorous concentration and the eutrophication of lakes. The concentration ranges given in Table 20 (Page 65), do not require extensive discussion as they show the same pattern as the ranges for the metal concentrations listed in Table 19 (Page 63). Mill Pond and the tailings seepages show the highest ranges, and all other parts of the site show ranges similar to those for Confederation Lake and the Mud Lake system.

For these elements however, it is more meaningful to compare the concentration ranges in Mill Pond and the tailings seepages to those reported in the literature for freshwater. Allen et al., (1974), give concentration ranges for aluminum of 0.2 to 2 mg/l, for calcium of 1 to 100 mg/l, for potassium of 0.5 to 20, for magnesium of 0.5 to 20 mg/l, for manganese of 0.001 to 0.08 mg/l, for sodium of 2 to 100 mg/l, for phosphorous of 0.005 to 0.5 mg/l, and finally, for

WATER QUALITY PARAMETERS FOR WASTE MANAGEMENT AREA
MAY- JULY 1986

AREAS	RANGES (mg/L) Al	Ca	K	Mg	Mn	Na	P	S
In Mill Pond	<0.01-36.1	211-247.3	0.63-4.81	14-39.1	13.6-12.8	2.5-4.9	<0.01-1.2	219-564
Mill Pond-Outflow	0.22-1.08	8.4-34.5	<0.005-6.0	11.3-5.44	0.12-1.02	1.4-2.5	<0.005-0.17	6.3-49
In Boomerang	0.2-0.83	45-63	<1-3.0	7.9-13	1.97-3.8	2.9-5.6	<0.005-0.46	50-61
In Lost Bay (C1-C4)	<0.005-0.17	7.1-13	<0.005-4.8	1.02-2.0	<0.005-0.31	0.74-1.2	<0.005-0.12	0.77-6.3
In Tailings Seepages	0.28-1.5	284-360	3-12.6	81.6-105	30.5-59.4	10-25	<0.005-0.58	569-820
Decant	<0.01-1.1	1.8-250	3-6	0.61-14	0.0006-1.4	5.4-486	<0.01-2.1	110-141
Mud Lake	0.01-0.42	22.4-97	0.52-3.06	1.62-9.2	0.04-0.28	1.9-6.1	<0.01-0.32	9.3-61
Mud Lake Outflow (E)	0.11-0.19	76.7-87.6	2.06-6.3	4.8-8.06	0.05-1.2	13.7-6.93	<0.005-0.02	30-52.2
Confederation (C7-C11)	<0.005-0.04	7.8-24.53	<0.005-3	0.12-2.35	<0.005-0.08	0.9-2.3	<0.005-0.41	0.91-10

Table 20: Concentrations of macroelements in surface waters in the waste management area of South Bay and its vicinity.

sulfur of 2 to 150 mg/l. Based on these values, and considering the maximum concentrations, the tailings seepages are high in calcium, magnesium, manganese and sulfur, reflecting conditions similar to those found in acid mine drainage. For Mill Pond, the concentration range of aluminum is also somewhat elevated. For the other elements however, Mill Pond displays the same characteristics as the tailings seepages. Decant Pond has extremely wide concentration ranges for some of these elements although, with the exception of Na, their maxima are considerably lower than those in the seepages and in Mill Pond. This might indicate that in Decant Pond point sources for sodium exist within the pond. This aspect should be considered when implementing close-out measures.

In summary, acidic drainage conditions are not evident in any locations on the site other than those where experiments are underway. This should facilitate the establishment of environmentally acceptable conditions for abandonment of the waste management area. The required measures axe discussed in the following section.

4.3 EXPERIMENTS FOR CLOSE-OUT MEASURES

4.3.1 The technical basis of Ecological Engineering and Biological Polishing measures

A brief outline of the chemical processes which cause acid generation is necessary to explain the significance of the experiments undertaken at South Bay. It will also provide the technical context for how the objective 'of elimination of causes of acid mine drainage may be achieved through the development of Ecological Engineering Methods and Biological Polishing Systems.

It is generally accepted that acid generation is a process consisting of three steps. The first step is mediated by chemical and/or biological oxidation of sulfide-containing minerals, and is described as:

$$FeS\ (s) + 7/2\ O_2 + H_2O = Fe^{2+} + 2\ SO_4^{2-} + 2H^+$$

The interaction of oxygen and water with waste rock, tailings or ore will inevitably lead to acidification of the material. Oxygen and water are readily available in the environment. However, reducing conditions (absence of oxygen) prevail in bogs, or below the root zone in wetlands. To inhibit this first step of acid generation, one must develop wetlands to cover the exposed waste material. The accumulation of organic matter will ultimately provide reducing conditions for the underlying waste material or for the acidified surface water.

After initial acidification has occurred, the lowered pH of the microenvironment creates a favourable habitat for acidophilic bacteria and, thus, leads to the second step of acid generation. In the presence of oxygen, these bacteria increase the oxidation rate significantly. Ultimately, chemical conditions are reached which set in motion the third step of acid generation. Ferrous iron is converted by microbial action into ferric iron and the solution in the material ultimately reaches a pH below 3. At this pH, ferric iron remains in solution, and acts as an oxidizing agent of pyrite, resembling the leaching conditions used in extracting metals. Thus, acid generation is finally limited by the concentration of ferric iron. Once this stage has been reached, the acid mine drainage leads to severe environmental degradation.

Since Thiobacilli (the main group of acid generating bacteria) require oxygen, reducing conditions will inhibit their activity. Reducing conditions, on the other hand, facilitate colonization of Desulfovibrio, a group of sulfur bacteria which utilizes sulfates for oxidation of organic matter. The sulfates are reduced by anaerobic respiration by the bacteria to hydrogen sulfide, commonly referred to as bog gas, with its typical smell of rotten eggs. Wetland conditions would serve to inhibit the second step in the process of acid generation and promote the development of favourable habitats for sulfate reduction. By reducing the part of the sulfate in the water, the acidity will not increase as far as it otherwise would, and the pH of the solution will gradually rise. It follows that if steps one and two of the acid generation process are curtailed, reducing conditions could improve the water quality.

Given the above-described processes, the question arises - how does one encourage formation of wetlands on mine sites if they are such a logical solution? Most waste sites are associated with various degrees of development of acid mine drainage, and these conditions do not generally support wetland plants. Ecological Engineering experiments, therefore, address the improvement of water quality by making amendments to support tolerant biota and the establishment and growth promotion of wetland species in acid mine drainage conditions.

4.3.2 Amendments

Sawdust experiment: The sawdust placement after removal of the precipitated from the liming activity is shown in Plate 9.

Plate 9. The Sawdust experiment in the outflow of Mill Pond

It is hoped that reducing conditions will develop in time, and also that the sawdust will provide adsorption sites for metals. During the summer, pH and electrical conductivity were monitored in the experimental area, and the results are summarized in Table 21 (Page 71). The pH in the sawdust was higher than in the channel leading to it by as much as one unit (more neutral) on various dates. It would be tempting to conclude that these observations are due to the sawdust amendment. However, in general, the pH variations in the pond are large and these pH values are at best a good indication of a trend in the right direction. The apparent increases in conductivity in the sawdust is a positive factor, suggesting some changes in the ionic composition of the water.

pH and Conductivity Associated with Mill Pond Sawdust Experiment

Date	Experiment	in sawdust		in channel		Range of the rest of pond	
		pH	cond	pH	cond	pH	cond
5\13	Preparation of channel			4.5	1000	4.0-5.0	900-1000
5\16	Placement of 20 bags of sawdust as a settling tes	11.9	-	5.1	1400	4.8-5.4	500-1400
5\27-6\08	Placement of @ 1/2 truckload of sawdust	-	-	-	-	4.1-5.7	600-1200
6\14	Placement of cattails	5.5	-	5.2	-	-	-
6\15	Water sampled	6.9	2400	5.8	1300	4.9	1300
7\08	Monitoring	7.5	-	5.9	-	-	-
7\20		6.0-6.8	-	5.5-5.6	-	6.2-6.8	-
7\21		6.2-7.8	1750-2500	-	-	-	-
7\23		5.8-6.2	1200	4.9	2350	2.9-5.7	1400-2000
7\27	After 2nd additio of @1/2 truckload of sawdust	6.0	1850	-	-	-	-
8\07	Monitoring	7.2	-	-	-	6.1	-
8\17		5.5-6.0	1900	-	-	6.2	-
10\18		4	2000	-	-	4.2	1100

Table 21: pH and conductivity measurements in the sawdust experiments in Mill Pond .

The sawdust was periodically sampled and analyzed for metals over the season. At the same time, dry sawdust was collected from a remnant pile which had not been exposed to the waste water in Mill Pond.

Given the large fluctuation of metal concentrations in the water and also of the water levels, improvements in water quality due to sawdust are unreliable indicators of the effectiveness of this amendment. An analysis of the solid material which was exposed to Mill Pond water, compared to that of the original material which had only been exposed to weathering, provides some indication of whether or not metals had been adsorbed by the sawdust. The differences in the concentrations of copper, iron, lead, zinc and sulphur in the sawdust are presented in Table 22 (below) for the months of July, August and October, 1986.

Table 22: CONCENTRATION DIFFERENCES OF METALS IN WET AND DRY SAWDUST

Date 1986	7/24	8/17	10/18
Metal		Percent difference[1]	
Copper	0.2	0.05	0.12
Iron	0.16	0	0.7
Lead	0.002	0.001	0
Zinc	0.1	0.1	0.16
Sulfur	0.2	0.07	0.2

[1]Percent content in wet sawdust - percent content in dry sawdust.

Sawdust is not a homogeneous material and each sampling will not result in the same concentrations of metals. Differences in concentrations between wet and dry sawdust for each sampling period, if the differences are persistent over an extended period, may indicate some general trend. The results of the subtractions are presented in Table 22 (Page 72). These values do indicate a trend, in that the wet sawdust is consistently higher in metal concentration, particularly for copper, sulfur, zinc and iron. For lead however, the differences are negligible.

These results, together with the pH and the conductivity changes noted, suggest that the desired effects of the sawdust amendment are being achieved. For example, for sulfur, each kg of wet sawdust contains 2 g more than the dry material. It is likely that the sulfur has been removed from the water and has been adsorbed on the sawdust in the form of a metalsulfate. Although the data to date are promising, continued measurements and analysis of this experiment will be required to ascertain if the ultimate aim of improved water quality and reducing conditions can be achieved.

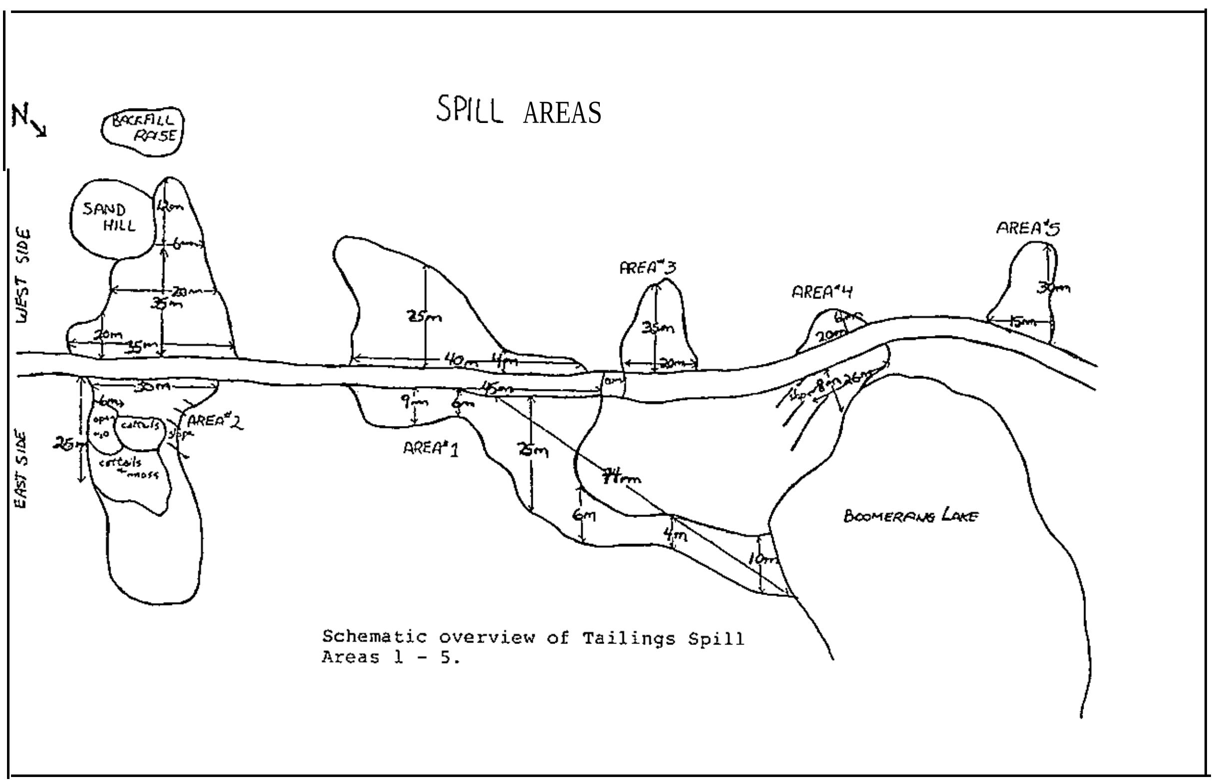
Water retention structures: The area of the sawdust experiment is small. Run-off during spring will certainly result in water escaping to the Mill Pond run-off ravine. A retention dam (Plate 10, Page 74) referred to as Dave's Dam, was built below Mill Pond. It is hoped that this dam will retain some fraction of the water from spring run-off to Boomerang Lake.

Plate 10: Dave's Dam below Mill Pond at the head of the ravine.

The upper part of the ravine will become a wetland, providing binding sites and **complexing** agents for metals, i.e. providing a Biological Polishing capacity for the spring run-off water. A detailed assessment of these measures will have to await the results of the spring run-off and water quality monitoring in 1987.

Covering exposed surfaces of tailings with water results in an immediate reduction of acid generation due to the reduction in oxygen penetration into deeper layer of the tailings. Several spill areas, which might contribute metals to Boomerang and

Confederation Lake have been investigated. In Schematic 2 (Page 75), these locations are indicated. Based on the depth of excavated pits which were dug until the original material was reached (organic peat layer), volumes of tailings were estimated. The estimates of the area and the volumes are given in Table 23 (Page 76).



Schematic overview of Tailings Spill Areas 1 - 5.

Schematic 2. Tailings spill area

Table 23: ESTIMATES OF AREAS AND VOLUMES OF TAILINGS SPILL

Area	Deadfall	Tailings	Tailings
#	m^2	m^2	m^3
1	1590	1265	200
2	1540	1465	709
3	700	16	7
4	164	164	55
5	450	-	-

Only areas 1 and 2 were considered to be of significant size for the implementation of remedial measures. In Area 1 (Plate 11, below), 5 dams have been built to accumulate water, using tailings material and deadfall. Lime has been applied to the top of the spillway. In 1987, experiments will be initiated to establish vegetation in the water, and it is hoped that the water will be retained from spring run-off.

Plate 11. View of spill area 1 where retention structures have been implemented, referred to as Harold's Dam

In area 2 (Backfill Raise), the tailings were treated with lime. A cover of waste rock, followed by sand, is intended to be placed over the surface. In 1987, the water characteristics which result from the neutralized and covered tailings will be compared to those previously determined for this site. It will be ascertained at that time if any further amendment steps are required.

4.3.3 Growth experiments

Water bodies are colonized naturally by wetland plants in response to several factors, some of which have been better documented than others (Wheeler, 1981). Some important physical factors are substrate conditions, water depth, seasonal water level changes and chemical factors which determine the ecological species composition, i.e. acidophile or calciphile species. In the colonization stage, the chemical and physical conditions of the water body are most important for plant seedlings to germinate and take root. Consequently, the establishment of plants in waste areas is frequently limited to localized areas of the waste site where conditions happen to be favourable for germination and establishment (Kalin and Caza, 1983). The first step in the establishment of a wetland is addressed by experimenting with methods to introduce vegetation to the waste water body.

Because of the extremely fine precipitate nature of the sediment, and of the depth of Decant Pond, it is necessary to employ hydroponic methods for establishing cattails, and thus promote the formation of a wetland cover. Two hydroponic methods have been tested, namely cattails planted in rafts, and root stocks suspended in fishnetting. Both methods appeared to fail in the first six weeks of the experiments. However, observations at a later date indicated that shoots are developing in both methods. After overwintering, survival of the floating structures and the cattails has to be assessed in 1987.

For Mill Pond it was necessary to find a mechanical method of transplanting cattails which would withstand the high fluctuations of concentrations of metals and water levels. Cattails were selected from four different source locations, which had varying degrees of cattail densities, from very dense stands to sparse stands. The pH ranged form 6.4 to 8.5 and the conductivities were below 100 umhos/cm for all locations with the exception of cattails taken from the edge of Decant Pond (700 umhos/cm). Cattails transplanted mechanically by front end loader retained considerable quantities of original root material in the transplanted location, whereas hand transplanted cattail individuals or groups (2 to 4) retained very little of the original root material. Growth was assessed by counting the total numbers of cattails transplanted and measuring their height; recounting and re-measuring the plants and their number of fruits after six weeks. An analysis of the effectiveness of the cattail transplant methods is presented in Table 24 (below).

EFFECTIVENESS OF HAND AND MECHANICAL TRANSPLANT METHODS - SUMMARY

LOCATION	TRANSPLANT METHOD	INITIAL DATA		FINAL DATA		
		TOTAL #	AVG. HEIGHT (cm)	TOTAL #	AVG. HEIGHT (cm)	# NEW SHOOTS
Mill Pond	mechanical	96	85.4	111(26F)	82.2	-
	hand	45	77.2	49(6F)	54.3/12	16
Decant Pond	mechanical	100	98.3	196(15F)	87.7	-
	hand	47	93.6	123(17F)	94/52.3	82
gravel pit	hand control	50	74.3	71(3F)	56.5	
Confed. Lake	mech. control	44	73.7	60	110.8	-
gravel pit	undisturbed control	17	106.6	16	74	-

Legend: average height = old/new shoots

Table 24: Effectiveness of hand and mechanical transplant methods

The differences in the characteristics of the source of the cattails and the changes they had to endure in the new locations to which they were transplanted, did not appear to affect their survival. On the average, the mechanical transplants in Mill

Pond and Decant Pond showed a survival of 71 $\pm$ 21 %, and the hand transplants 86 $\pm$ 23 percent.

The differences between the initial and final measurements suggest that the hand transplanted numbers increased considerably, which is indicated by the number of new shoots which developed since transplanting took place. For the mechanical transplants, it was not possible to determine new shoots, since the individual plants were not marked. The mechanical transplant method, compared to the hand transplant, has one distinct disadvantage. 'It can only be used on shores where access of the front end loader is possible. Both methods result in cattail survival and may be used selectively depending on access in establishing cattails in the desired locations.

Reproduction in both the mechanical and hand transplanted populations in Mill Pond and Decant Pond is higher than in the control transplant and undisturbed populations (Gravel Pit, Confederation Lake). A high number of fruiting cattails in a population has been found to be indicative of environmental stress (Kalin, 1984), and is typical for cattail populations on waste sites.

In summary, the results of these experiments indicate that during the summer season hand-transplanting will result in new shoots and, consequently, this measure was taken for Mill Pond in August 1986.

Plate 12: Hand transplanted cattails in Mill Pond.

4.3.4. Biological polishing: Metal removal

It was clear from the chemical characteristics of Boomerang Lake and Decant Pond that processes are needed to remove dissolved metals in order to improve effluent water quality in the long term. Based on the study of the recovery of abandoned tailings areas, mechanisms of this nature, termed Biological Polishing processed, are frequently encountered (Kalin and Smith, 1984).

In addition to Ecological Engineering methods, site specific Biological Polishing mechanisms have to be identified and described. Once mechanisms, specific to each water management area, are understood, measures can be taken t promote their effectiveness as part of the abandonment plan for a self-sustaining recovery of the waste site.

In Table 25 (below), a summary of concentration factors for periphytic algae (attached algae) occurring in Boomerang Lake and Decant Pond is given for copper, iron, lead and zinc. The algal mats consist of Mougeotia, Ulothrix, Phormidium spp. and diatoms (Bacillariophyceae) in both locations. In Decant Pond they form thick floating mats (2 to 3 cm), which extend over large fractions of the shallow parts of beaches, among the cattail stands. In Boomerang Lake, thick layers of brown "jelly like" algal mats coat shallow beaches and provide a dense cover over any wood deadfall which is in contact with the lake water.

The concentration factors presented in Table 25 (below) are derived by dividing the concentrations of these metals in the algal material by their concentration in either the water or the sediment. The resulting ratios or factors indicate whether the algae are concentrating the metal from the water or from the sediment, or if metals are present in the same proportions. Generally, concentration factors greater than 1, indicate adsorption or uptake of the metal from the water, i.e. the algae perform a biological polishing function.

Table 25 : COMPARISON OF CONCENTRATION FACTORS OF PERIPHYTIC ALGAE.

	ALGAE/WATER		ALGAE/SEDIMENT	
Metal	Boomerang	Decant	Boomerang	Decant
COPPER	26,003	197,500	7.6	2.2
IRON	85,000	78,000	2.7	0.6
LEAD	10,000	80,000	0.7	0.9
ZINC	700	12,000	1.4	1.5

The concentration factors found in the algal material and in the water are very large, as metal concentrations in the biomass are at least an order of magnitude greater than those in the water. The water content of the algal mats was estimated at approximately 90 to 85%. Even taking this factor into consideration, the concentrations of metals in the algal matter are considerable.

The concentration factors for metals in water by periphyton growth are high, both in Boomerang Lake and Decant Pond. To guard against an over-interpretation of the removal process of the metals from the water, the concentration factors have also been calculated, based on the concentrations in the sediment. It is important to realize that the periphytic algae are not rooted, making uptake from the sediment highly unlikely. Nevertheless, particulates could adhere to the extensive surface area of the periphytic mats, thereby distorting the removal process.

For the periphytic growth in Boomerang Lake, the concentration factors (algae/sediment, Table 25, Page 82) indicate concentrations in the algae seven times higher for copper and 1.5 times higher for zinc. The sediment concentrations in Decant Pond and those of the periphitic mats are in the same range, given that their concentration factors range from 0.6 to 2.2. A sample of the mat, collected a second time in October, 1986, was dried, ground and fractionated into sandy and fine portions. The concentrations of copper were 0.5 and 0.6%, iron 5.8 and 6.7%, lead

0.06 to 0.07%, and zinc 5.3 and 5.0% respectively, in the sandy and fine fractions analyzed. The metal concentrations in Decant Pond sediment are in the same ranges (Table 8, Page 39). It is clear, therefore, that the biological polishing capacity of the periphytic mats is confirmed for zinc, iron and copper.

These concentration factors, which were determined specifically for Boomerang Lake and for Decant Pond, strongly indicate that removal of copper, zinc and iron is occurring from the water to the periphitic growth. The next step to be addressed in 1987 is to quantify the polishing ability and promote growth of this periphytic community to increase its effectiveness in the removal of metals from the water.

Biological polishing ability has further been found to be associated with two species of aquatic mosses particularly suited for acidified water bodies (Kalin & Buggelin, 1986). One of the species Depanocladus fluitans was located in a water-covered portion of spill area #2. It was transplanted to the beach at the discharge of Mill Pond run-off. The moss was placed in bags made of netting, which were fastened to the sediment with stones. Considerable growth emerged from the bags after 2.5 months of placement. The over-wintering success of this transplant method will be evaluated in 1987. Based on the results obtained, it is anticipated that moss carpets will be established to serve as "filters for the beaches on the spill areas and for Mill Pond run-off.

The behaviour of zinc, described earlier, suggested that the main process controlling removal of zinc from the water column is the presence of particulate matter. Phytoplankton can be considered as one form of particulate matter, and can be expected to assist in zinc removal from the water column to the sediments in Boomerang Lake.

In Table 26 (below), a summary of some parameters of the phytoplankton populations are presented for Confederation Lake and Boomerang Lake.

Table 26: **CHARACTERISTICS OF PHYTOPLANKTON POPULATIONS**

CONFEDERATION LAKE

SITE \ DATE 1986	Mid-June			Late July		
	TAXA	CELLS	**BIOMASS**	**TAXA**	**CELLS**	**BIOMASS**
Cl	38	99.3	279.8	38	62.8	251.8
C8	26	233.9	655.6	-	-	-
Cl1	32	119.7	508.3	43	58.4	282.9

BOOMERANG LAKE

	Early June			Mid-June			Late July		
	TAXA	**CELLS**	**BIOMASS**	**TAXA**	**CELLS**	**BIOMASS**	**TAXA**	**CELLS**	**BIOMASS**
B1	12	68	61	-	-	-	19	96	121
B2	10	50	94	24	104	165	20	37	40
B3	11	76	93	22	52	124		57	76
B4	12	28	38	27	77	133	12/20	28	66
B5	10	34	55	23	32	83	18	79	133
B6		-	-	21	78	119	15	47	76
B7		-	-				11	14	13
B8		-	-				10	47	55
B11		-	-	30	96	211	15	49	64

Units: Taxa = **number** of genera: Cells = x 10^4 **cells /L**
Biomass estimates in **(ug/L)**

The sampling locations for phytoplankton are the same as those for surface water given in Map 7 (Page 33). Sites were selected at the discharge of Boomerang Lake to Lost Bay (Cl), at the mouth of the Mud Lake system (C11) in Confederation Lake, and in the bay which could receive run-off or seepage from the mine and mill site (C8).

Identifications were made to the genus level and, where possible, to the species level, and were summarized as the number of taxa present in each sample. The number of taxa is an indication of the variety of genera present in the population. Phytoplankton populations with a higher variety are considered to occur in waters where environmental conditions support a broad spectrum of growth requirements. A lower variety of genera or species is expected in waters with growth limitations.

The number of cells is calculated based on a count of a subsample and provides an approximation of the population density. The third descriptor is biomass volume, which is estimated based on the cell volume of the genera or species. Biomass is a descriptive parameter which expresses some fraction of the content of particulate matter in the water.

In Confederation Lake, samples have been evaluated for the mid-June and late July collection, suggesting differences in time and between the sampling stations. Stations Cl and Cl1 are very similar in both the number of taxa present and the number of cells. The biomass volume was higher at C8 in mid-June, but was similar in late July. It is possible that these differences between the stations are a reflection of the different types of water. Both Cl and Cl1 are shallow (approx. 0.5 m deep) and the sample was a dip sample, whereas the sample from station C8 is an integrated tube sample. Such a sample consisted of phytoplankton collected from the upper 2.5 meters of the water column. In Boomerang Lake, stations B1, B2, B6, B7, B8 and B11 are shallow dip samples, and integrated tube samples were collected at stations B3, B4 and B5.

The differences between the sampling sites and the sampling time within Confederation Lake and Boomerang Lake reflect the expected dynamics of phytoplankton populations. An important aspect for the purpose of this assessment is the relative differences in these parameters in the two water bodies. The number of taxa, the number of cells and the biomass volume is higher in Confederation Lake than in Boomerang Lake. The number of taxa increases in Boomerang Lake by Mid-June and remains quite constant thereafter.

The stations are arranged in sequence from those farthest away from the tailings dam (B1) to samples from tailings beaches (B7 and B8) close to the run-off from Mill Pond. No striking differences can be noted between the stations, and it is probable that water depth and temperature contribute more to the noted differences in the populations present in these locations than could be due to any potential effects of contaminants from the waste site.

In general the phytoplankton community has a lower diversity and therefore a lower number of cells and biomass in Boomerang Lake than in Confederation Lake. This is expected given the acidification of the water and the metal concentrations. However, relatively speaking, the phytoplankton community is quite diverse and provides some particulate matter in the lake.

Furthermore, the composition of the phytoplankton populations could be evaluated to determine the effects of the waste water at the discharge points to Confederation Lake. Such an analysis would require the identification of indicator species specific to the water in the South Bay vicinity. In Table 27 (Page 89), the dominant genera or species are listed for the Boomerang Lake stations and those for the discharge points in Confederation Lake. The presence of a dominant member of the population is indicated with an 'X'. Two x's indicate that their numbers increase/decrease significantly between the sampling dates. The lines highlight the absence of the species from Boomerang Lake compared to those present in the Confederation Lake stations. There are two species which occur only at station C11, the discharge from the Mud Lake systems. Euglenophyceae, typical for acidic water, are found mainly in Boomerang Lake and are virtually absent in the Confederation Lake populations. It appears that particularly the presence of the Desmids and some members of

Table 27: PRESENCE/ABSENCE OP ALGAL SPECIES DURING SUMMER
May -July 1986

ALGAL TAXON	Boomerang B6	B5	B4	B3	B2	B1	Confederation C1	C8	C11
CYANOPHYCEAE									
Anabaena spiroides	—	—	—	—	—	—	X	X	X
Caelosphaerium kuetzingianum	—	—	—	—	—	—	X		X
Unidentified spp.			X		X		X	X	X
CHLOROPHYCEAE									
Chlamydomonas spp.	xx	xx	xx	xx	xx	xx	x		X
Mougeotia spp.		x	x	x			x		X
Oocystis submarina		X	X	X			XX	XX	X
Scenedesmus acutus	—	—	—	—	—	—	X		X
Sphaerellopsis cylindrica	XX	XX	X	XX	X	XX			
Ulothrix spp.	X	X	X	X	X	X	X		
Unidentified spp.	X	X	X	X	X	X	XX	X	X
Desmids									
Arthrodesmus incus	—	—	—	—	—	—	X		X
Cosmarium spp.	—	—	—	—	—	—	—	—	X
Staurastrum sp. (10 arms)							X		X
Staurastrum sp. (6 arms)							X	X	X
EUGLENOPHYCEAE									
Euglena mutabilis	x	x	x	x	x	x	—	—	—
Euglena *pp.		X				X	X		
Trachelomonas volvocina	x	x	xx	x	x	X	—	—	—
CHRYSOPHYCEAE									
Chromulina spp.	X	X	X	X	X	X	X	X	X
Dinobryon bavaricum	—	—	—	—	—	—	—	—	X
Dinobyron sertularia			—	—			X		X
Mallomonas sp.		—	—	—			X		X
Ochromonas spp.	x	x	x	x	X	X	X	X	x
Synura sp.	—	—	—	—	—		X		X
Unidentified spp.	x	x	x	x	x	X	X	X	X
BACILLARIOPHYCEAE									
Achnanthes linearis	x	x	x	x	x	X	X	X	X
Achnanthes minutissima	x	x	x	x	x		X		
Asterionella formosa		X		X			X		X
Asterionella ralfsii	—	—	—	—	—	—	X	X	X
Eunotia lunaris	X	X	X	xx	X	x			x
Fragilaria crotonensis					X	X	X	X	X
Fragilaria sp.		X	x				X	X	X
Melosira islandica	X	X	x	x	X	x	x	X	X
Melosira italica	X	X	X		X		X	x	X
Navicula spp.	X	x	X	x	x		X	x	X
Nitzschia spp.		X	x	X	X	x	X	X	X
Pinnularia mesolepta	x	X	X	X	X		X	X	
Pinnularia spp.	X	x	X	x	x	x	x	X	x
Rhizosolenia longiseta							X	X	X
Rhopalodia sp.	X	XX	X	XX	x	X	x	x	
Stauroneis sp.	X	x	X	X	x		X		X
Synedra acus	X			X	X		x	X	X
Synedra spp.		x	X	X			X	X	X
Tabellaria fenestrata	X	X	x	x	X		X	X	xx
Tabellaria flocculosa	X	X	X	X	X		X		X
Tabellaria quadriseptata		x				X	X		X
Unidentified spp.	x	X	X	X	X	X	x	X	xx
CRYPTOPBYCBAE									
Cryptomonas erosa		X	xx				X	X	X
Cryptomonas ovata						X	x	X	X
Rhodomonas lacustris			—	—			X		X
Rhodomonas minutus	—	—	—	—	—	—	x		x
DINOPBYCEAE									
Ceratium hirundinella	—	—	—	—	—	—	X		X
Peridium inconspicuum							X		X
Peridinium sp.		—	—	—	—		X		X

the Cryptophycea and the Dinophyceae in the discharge areas of Confederation Lake indicate that there is no evidence that the waste waters have affected the phytoplankton populations.

The same type of analysis of the phytoplankton community was carried out to determine if, within Boomerang Lake and possibly Decant Pond, differences in composition were apparent. In Table 28 (Page 91), the samples from the mid-July collection are analyzed and the data are presented using the same symbols as in Table 27 (Page 89). The presence and absence of these species in these stations, representing tailings spill beaches and the discharge from Mill Pond run-off, reflect the same pattern as that for Boomerang Lake. It is suggested, therefore, that the phytoplankton community is not affected by specific locations such as tailings beaches or spills, and is truly representative of Boomerang Lake.

Table 28: **PRESENCE/ABSENCE** OF ALGAL SPECIES IN RELATION TO TAILINGS VICINITY
July 1986

ALGAL **TAXON**	Decant Pond	B6	B7	B8	**B11**
CYANOPHYCEAE					
Anabaena spiroides					
Coelosphaerium kuetzingianum	—	—	—	—	—
Unidentified **spp.**	—	—	—	—	—
CHLOROPHYCEAE					
Chlamydomonas spp.	X	xx	xx	X	x
Mougeotia spp.	xx			X	X
Oocystis submarina	X				X
Scenedesmus acutus	X				
Sphaerellopsis cylindrica	x	xx	X	xx	xx
Ulothrix spp.		X	X		
Unidentified **spp.**	x	X	X	X	x
Desmids					
Arthrodesmus incus	—	—	—	—	—
Cosmarium spp.	—	—	—	—	—
Staurastrum sp. (10 arms)	—	—	—	—	
Staurastrum sp. **(6** arms)		—	—		
EUGLENOPHYCEAE					
Euglena mutabilis		X		X	X
Euglena spp.	X				
Trachelomonas volvocina		X	X	X	X
CHRYSOPHYCEAE					
Chromulina spp.	X	X	X	X	X
Dinobryon bavaricum	—	—	—	—	—
Dinobyron sertularia			—	—	
Mallomonas sp.					
Ochromonas spp.	X	X	X	X	X
Synura sp.		—	—		
Unidentified **spp.**	X	X	X	X	X
BACILLARIOPRYCEAE					
Achnanthes **linearis**		X	X		X
Achnanthes **minutissima**	X	X			
Asterionella formosa	—	—	—	—	—
Asterionella ralfsii					
Eunotia lunaris	X	x	X	X	X
Fragilaria crotonensis	- - -	- - -	- - -	- - -	
Fragilaria sp.	—	—	—	—	
Melosira islandica		X			
Melosira italica		X			
Navicula spp.		X			X
Nitzschia spp.	X				
Pinnularia mesolepta		X			
Pinnularia spp.		X			X
Rhizosolenia longiseta			—		
Rhopalodia sp.		x			
Stauroneis sp.		X			
Synedra acus	X	X	X		
Synedra spp.	- - -	- - -	- - -	- - -	
Tabellaria fenestrata		X			
Tabellaria flocculosa		X			
Tabellaria quadriseptata	- - -	- - -	- - -	- - -	
Unidentified **spp.**	X	X			
CRYPTOPHYCEAE					
Cryptomonas erosa					X
Cryptomonas ovata		—	—	—	
Rhodomonas lacustris	—	—	—	—	—
Rhodomonas minutus	—	—	—	—	—
DINOPHYCEAE					
Ceratium hirundinella	—	—	—	—	—
Peridium inconspicuum	—	—	—	—	—
Peridinium sp.	—				

5. CONCLUSIONS

It is essential to any endeavour to establish an environmentally acceptable close-out plan to understand and evaluate the long-term implications of those actions taken and events occurring to date. Some conclusions can be drawn from the results of our investigation of the various components of the waste management area of the South Bay Mines operations which provide some insight into the remedial steps which must be taken to achieve this goal.

Degradation of the environment in the immediate vicinity of the South Say Mine site was not evident from the evaluation of the water quality at any of the potential discharge points from the site to Confederation Lake. These locations are the outflow of Boomerang Lake, the mine site beach (Spill area 2 or Backfill Raise) and the Mud Lake system. At all three locations, the phytoplankton community consisted of several taxa members (Chlorophytes, Chrysophytes and Dinoflagellates) which would have been absent had the waters been contaminated. One of the strongest indicators of clean water are desmids, specifically the genus Staurastrum (Liebmann, 1962), which genus was present in all the samples from Confederation Lake and in those from the discharge paints. No evidence of contamination events which had occurred in the past was found in the characteristics of the sediments in Confederation Lake, Boomerang Lake and the Mud Lake system. Typical concentration ranges for mineralized areas were determined in the above-mentioned lakes, and only where tailings material formed the bottom sediment sediment were the concentrations higher than the natural ranges. This is the case for Decant Pond and for a small tailings spill in Boomerang Lake.

Given these excellent environmental conditions of the site, particularly in view of the fact that ten years of mine operation and four years since the cessation of operations have elapsed, it is reasonable to conclude that for purposes of close-out and final abandonment, the only measures required are those to prevent potential environmental degradation in the long term. It is anticipated that any future environmental degradation occurring in the vicinity of the mine site will only be brought about from unourtailed acid generation and the associated metal release, mainly that of zinc.

It was determined from an investigation of the chemical composition of surface water on the mill site and water emerging from the tailings area in direct contact with the tailings, that these are the main sources of contamination. It is these locations then and their associated sources of contamination which must be considered the main focus in our search for suitable close-out measures.

Although the acidification of Boomerang Lake and its zinc concentration have been the main points of concern to date, an investigation of chemical and biological factors strongly indicates that recovery of Boomerang Lake can be achieved by reducing or curtailing contaminant loads from the mill site, the spill areas and the tailings.

Furthermore, biological polishing processes have been identified in the lake and Decant Pond (periphytic algal growth and aquatic moss carpets) which will assist to improve, over time, the water quality. It is anticipated that the measures which are being taken to enhance these processes will, together with the presence of a phytoplankton community characteristic of lakes which have been affected by acid precipitation, be effective in removing zinc from the water column.

Three distinct areas for remedial measures are identified, namely, the mine site, spill areas and the Decant Pond. The measures are intended to be self-maintaining and effective in the long term by polishing water which will continue to emerge from the tailings. The seasonal changes noted in metal concentrations during the year, for example in Decant Pond, the Mud Lake system and Mill Pond run-off area, require further investigation as part of the implementation of close-out measures of the site. It is suspected that the fluctuations in water quality are mainly associated with spring and autumn run-off conditions.

From the preliminary growth results of ecological engineering experiments carried out during the investigation, with cattail transplant methods and amendments to the water in Mill Pond, it can be concluded that the site conditions are suitable for the development of reducing conditions. It is conceivable that these will eventually be present in the form of wetlands with a dense layer of organic matter, located strategically in areas of main water flow from the tailings. These wetlands will provide on-site containment of metals, as well as reducing conditions for the acid which is expected to generate in the long term.

Preliminary hydrogeological investigations carried out last summer indicated that surface seepage was occurring from the tailings containment dams into Boomerang Lake. The hydrogeological assessment suggested not only a flow to Boomerang Lake, but the presence of a complex water regime, i.e. several flow directions. These findings need to be substantiated prior to the implementation of Ecological Engineering measures for abandonment purposes. The objectives of such a study would be to identify the water flow in order to determine the locations at which the polishing/retention wetlands should be established for the most effective treatment of acid drainage.

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